Home Water Treatment

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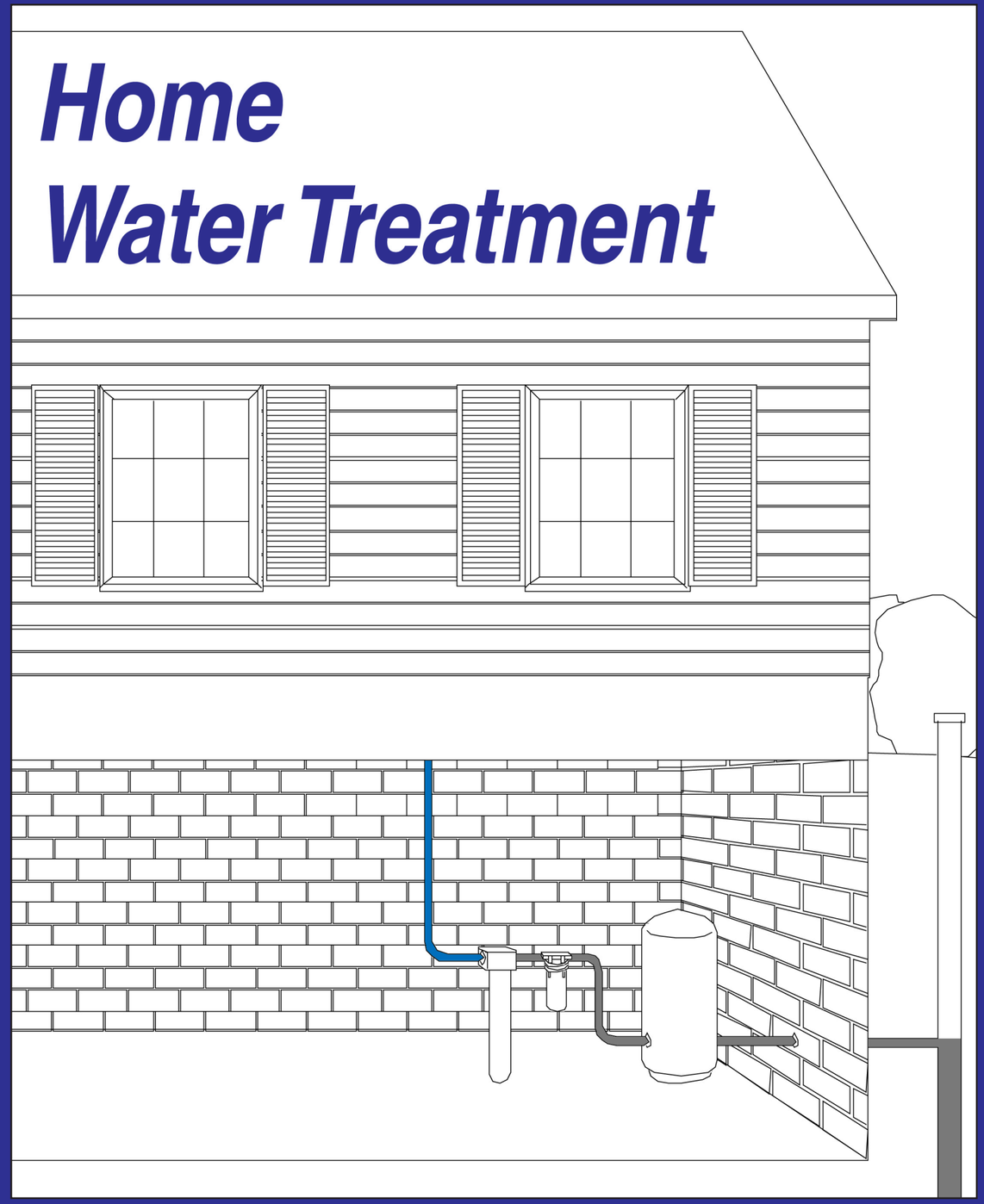

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Introduction

Drinking water quality is a common concern among homeowners today. The quality of municipal drinking water is regulated by the U.S. Environmental Protection Agency (EPA) and some state agencies. But individuals who drink from private waters such as springs, ponds, wells, and cisterns are responsible for monitoring the water they drink. Few states mandate that individual supplies be tested and treated.

A water test can confirm the presence of contaminants in a private water supply. If a supply is found to be contaminated, water treatment is one option. It can improve drinking water safety by killing harmful organisms or by reducing the concentration of contaminants. It can also improve the aesthetic quality of water. For instance, hydrogen sulfide, the "rotten egg" gas, can be removed via home water treatment. The selection of a treatment device or system should be based on a case-by-case technical evaluation and on an economic assessment.

Homeowners have other options to consider besides water treatment. It may be possible to avoid contamination by better protecting the water supply or by eliminating the source of contamination. Other alternatives are to find a new water source or to buy bottled water for drinking and cooking. If the contaminants do not affect health, it may be more economical to simply live with the problem.

About This Publication

This publication is a reference about common home water treatment devices. Homeowners on private water supplies can reference it to find the device or system appropriate for treating contaminants. Others can use it in educational programs. It is also designed as a desk reference for cooperative extension agents, regulatory personnel, and industry professionals. Individuals on public water systems may find the information useful for improving the aesthetic quality of water or for treating contaminants that may leach from household plumbing.

Chapter 1 reviews the basics of water treatment and includes common terminology and a table that summarizes possible water treatment methods for various contaminants. Chapters 2 and 3 present physical and chemical home water treatment devices, their effects on water quality, and their basic principles of operation. Although maintenance requirements and capacity vary by device design and construction, general statements for each type of device provide information to help homeowners decide whether to purchase a device. Any special considerations, such as controversy about the safety of a particular device or state laws that restrict the use of certain devices, are given as appropriate. The last section, entitled "Final Thoughts," summarizes the text and discusses the future of the water treatment industry.

Three appendixes provide information on drinking water contaminants and will help homeowners interpret a water test report, pinpoint which contaminants exist in a water supply, and, if necessary, choose an appropriate treatment technology. A fourth appendix lists conversion factors. A glossary is included beginning on page 103; terms are defined within the context of home water treatment. Finally, a reference section lists documents the authors consulted in the development of this publication.

Water Quality and Water Testing

Private Drinking Water Supplies: Quality, Testing, and Options for Problem Waters, NRAES–47, is a companion to this publication and serves as a general reference on drinking water quality. (For ordering information, please see page 120.) It includes information about water quality standards, water testing, land use practices that affect water quality, and options for problem waters. The following is a summary of the information in NRAES–47.

Water Quality

The EPA has standards for municipal water supplies that are useful in determining if water treatment is justified for private supplies. The EPA's Primary Drinking Water Standards concern hazardous contaminants and define the Maximum Contaminant Level (MCL) allowed in municipal drinking water supplies. Homeowners can use the standards as a guide to assess the quality of private water supplies.

The EPA's Secondary Drinking Water Standards concern substances that affect the aesthetic quality of water and can be used to evaluate the suitability of a water supply for drinking and other domestic uses. They include standards for taste and odor; chemicals that stain clothes or plumbing fixtures; and contaminants that cause cosmetic effects, such as teeth or skin discoloration, if consumed for an ex-

tended period. Secondary standards are not enforced by the federal government but may be enforced by some state or local governments for municipal supplies.

If a substance is not included in the standards, it may still pose a health risk or affect the aesthetic quality of water. A standard is set only when enough information is available to justify it. Even after researchers obtain the necessary data, the process of creating a standard can take several years.

The EPA issues health advisories for drinking water contaminants that are not yet covered by the standards. Health advisories summarize current, acceptable contaminant levels in drinking water. Different levels are set depending on the duration of consumption and on whether a child or an adult consumes the water.

Appendix A summarizes the EPA's Primary Drinking Water Standards and health advisories. Appendix B lists the EPA's Secondary Drinking Water Standards. Potential treatment technologies, as recommended in the standards and health advisories, are also included in appendixes A and B. Appendix C lists names of pesticide products that contain EPA-listed drinking water contaminants.

Water Testing

Water testing determines if a water supply is contaminated. Regular testing of private water supplies is not mandated by the federal government, although some states or lending institutions require testing when a home is sold or when a new water supply is developed. The homeowner is responsible for routine water testing and an awareness of local land use practices that may contaminate the water supply. Such practices may include mining, excessive land application of sludge or nutrients, or improper waste storage or disposal.

Homeowners should test water supplies annually for total coliform bacteria, nitrate, pH, and total dissolved solids (TDS). These routine tests help identify changes in water quality due to microbiological contamination and some land use practices.

For most organic chemicals, even minute concentrations in drinking water may affect health if the water is consumed over a number of years. Routine tests do not pinpoint organic chemical contamination; other specific tests are necessary if homeowners suspect the presence of such chemicals based on current or past land use practices.

Further testing is necessary if potential for contamination from local land use practices exists, if recurring health problems may be caused by contaminated water, if a neighbor's well is discovered to be contaminated, if household plumbing contains lead, or if water quality changes noticeably. Periodic testing is recommended to assure that a treatment device is working properly. In addition, it is important to test water before purchasing a home that has a private water supply to determine whether water treatment equipment may be an additional expense.

If a particular contaminant such as lead or benzene is suspected, it is necessary to test specifically for that contaminant. For contaminants included in the EPA's standards or health advisories, the contaminant concentration in the untreated water should be compared to the maximum concentration listed in the standard to determine if the water supply is unsafe or of unacceptable quality. Knowing the contaminant concentration is helpful when selecting treatment equipment.

An EPA or state-certified laboratory should conduct the water test if a contaminant that is a health hazard is suspected. Many water treatment companies offer complimentary in-home testing, but such tests are appropriate only for nonhazardous contaminants. Homeowners should be wary of in-home tests that claim to determine more than the level of hardness, pH, iron, sulfur, and TDS.

Water tests are never 100 percent reliable. If a test shows that a water supply has an unacceptable level of a contaminant, the water should be tested again to confirm the results. It is crucial to follow laboratory instructions when collecting samples.

Test the Water

- when a new water supply is developed
- yearly for coliform bacteria, nitrate, pH, and TDS
- if potential for contamination from local land use practices exists
- if recurring health problems may be caused by contaminated water
- if a neighbor's well is contaminated
- if household plumbing contains lead
- to assure that water treatment devices are working properly
- before property exchange

1 The Basics of Water Treatment

Water treatment options include passing water through a treatment medium, heating it, exposing it to ultraviolet light, adding a chemical to it, or a combination of these. When choosing a treatment system, identify the device best able to solve the water quality problem. Choose a device that offers an acceptable level of treatment and a manageable maintenance schedule.

Home Water Treatment Language

A variety of terms describe water treatment devices, their maintenance requirements, and their efficiencies of operation. Point-of-entry (POE) devices treat all the water coming into the house. Point-of-use (POU) devices treat the water at a single tap or multiple taps but not water for the entire household; these devices are generally used to treat water used only for drinking and cooking. Devices may also be in-line, line-bypass, or off-line. In-line devices are installed in the water supply line and treat all water moving through the line. Line-bypass units treat water diverted from the cold water line and supply treated water through a separate treated water faucet. Untreated water is available while the treatment unit is being serviced. Off-line devices are not connected to the water distribution system. An example of an off-line device is a countertop distiller to which untreated water is added manually.

The capacity of a device has two components: the flow rate capacity and the contaminant removal capacity. Flow rate refers to the rate of water flow through a device and is measured in gallons per minute or gallons per day. One gallon per minute is equal to 1,440 gallons per day. The most important flow rate capacity is at normal household water pressure, which is about 30 to 60 pounds per square inch. Assuming a water pressure of 30 pounds per square inch, the minimum initial flow rate acceptable for a line-bypass unit with a treated water storage tank is 2 gallons per day; for a line-bypass unit without a storage tank, it is 0.2 gallons per minute; for an in-line, single-tap unit without a storage tank, it is 0.5 gallons per minute; and for an in-line POE unit, it is 4 gallons per minute. These rates are based on minimum service flow rates stated in standards set by the National Sanitation Foundation (NSF). [See the section entitled "The National Sanitation Foundation (NSF)" on page 7.]

Flow rate is affected by the pressure drop, which is the difference in water pressure between the inlet and outlet sides of a treatment device or between the outlet of a treatment device and a faucet. Excessive pressure drop causes decreased water flow at faucets. Most home water treatment devices are designed for installation in a pressurized water distribution system. For municipal water supplies, the distribution system supplies the water pressure. For well water, the well pump sup-

plies the water pressure. For surface water supplies, a pump supplies the pressure unless the water source is at a higher elevation than the home—then gravity supplies the pressure. Figure 1.1 illustrates a natural gravity water system.

The contaminant removal capacity refers to both the percent reduction in a contaminant concentration between the untreated and treated water and the total amount of contaminant a device can remove before maintenance is required. Before purchasing a device, review the product information to assure that the unit will reduce the contaminant concentration to a desirable level and maintain that level for a reasonable period of time without excessive maintenance. Water treatment salespeople have information about selecting devices to achieve the necessary contaminant removal capacity.

A common contaminant is suspended solids. Suspended solids may either be visible as individual particles or they may give water a cloudy appearance. Suspended solids include silt or clay; decayed plants or other organics; and iron, manganese, or sulfur particles. Microorganisms are also considered suspended solids. Suspended solids result in turbidity, which gives water a cloudy appearance. Suspended solids may interfere with water treatment, because they shield microorganisms from disinfection agents and may adsorb contaminants. Suspended solids may also clog certain home water treatment devices.

A properly operating device reduces the concentration of a particular substance to a safe or acceptable level. Breakthrough occurs when the contaminant concentration in the treated water rises above that level. Some devices, when allowed to operate beyond breakthrough, may actually start releasing contaminant into the water, resulting in a higher contaminant concentration in the treated water than in the untreated water. This is referred to as unloading, or dumping.

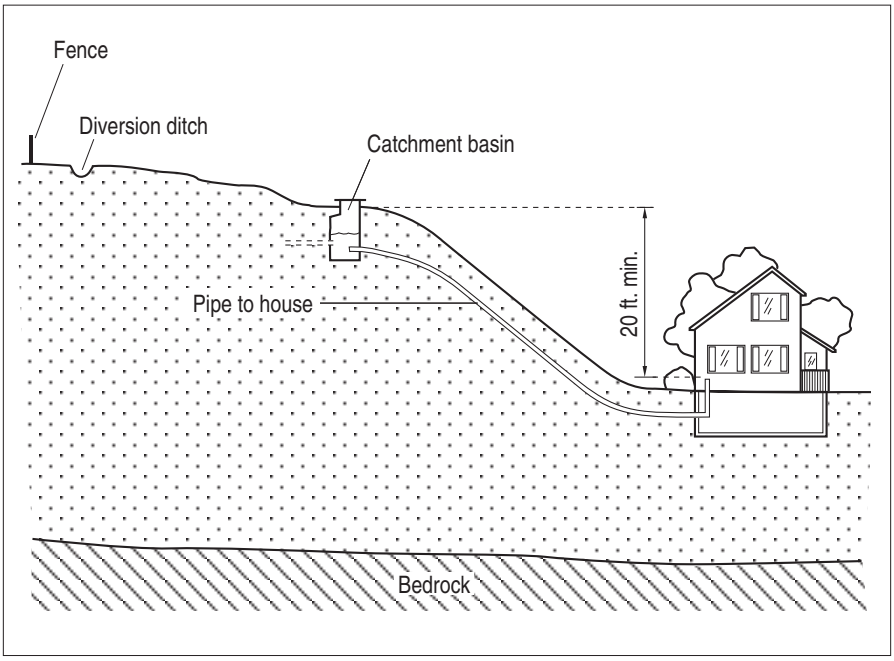

Figure 1.1
Gravity water system.

Note: For a satisfactory flow, there should be at least a 20-foot elevation difference between the spring and the highest faucet. If the distance to the spring is great, more than 20 feet would be desirable to account for pressure loss in the pipe.

Depending on the quality of the untreated water and the desired treated water quality, pretreatment or posttreatment may be required. Pretreatment involves installing additional treatment devices before the primary device and is most often required when untreated water contains suspended solids that may shield microorganisms from disinfection or clog devices. Posttreatment involves installing additional devices after the primary treatment device. Posttreatment will remove any lingering chlorine taste or smell after chlorination or adjust the pH, which may rise or fall to an unacceptable level after certain water treatment methods.

Preferential treatment occurs when untreated water contains several substances that are removable by the treatment device being used, but the device prefers one substance over another. For example, an anion exchange unit prefers sulfate over nitrate. If the anion exchange unit is installed to remove nitrate, and the untreated water contains both nitrate and sulfate, the system's capacity for nitrate removal diminishes (see section on anion exchange, page 45).

Backwashing is a maintenance procedure required for some treatment devices when the contaminant removal capacity of the device has been exhausted. Backwashing reverses the normal water flow direction through a treatment device and flushes out substances that have accumulated in the device.

Regeneration, another maintenance procedure, is required for water softeners and other ion exchange devices. During regeneration, a concentrated solution called the regenerant is passed through the treatment device. The regenerant removes any retained contaminants from the device and replenishes the contaminant removal capacity. Regeneration is sometimes loosely referred to as backwashing.

Many treatment devices require a minimum contact time between contaminants and the treatment medium. For adsorption processes, the contact time is the amount of time the water must be in contact with the adsorption surface (see section on adsorption processes, page 24). For treatment involving chemical reactions, it is the time required to complete the reaction between the treatment chemical and the untreated water. Contact time is especially important for disinfection by chlorination (see page 47).

Determining Household Water Needs

Determining the water needs of a home is an important step in selecting a water treatment system. Systems vary in the amount of treated water they provide. Generally, the more water that needs to be treated, the larger and more expensive the required treatment system. Plumbing changes may lessen the load on treatment equipment by diverting some untreated water to flush toilets or water lawns. Table 1.1 can help estimate a household's daily water use.

Home Water Treatment Systems

Some water quality problems require a treatment system comprising multiple devices. As a general rule, when a treatment system is necessary and untreated water contains suspended solids, mechanical filtration should be the first step in the system. Fine sand, silt, or other particulates can clog water treatment devices and shelter bacteria from disinfection. Beyond this recommendation, it is difficult to generalize about the preferred order of treatment devices. Much depends on what contaminants need to be removed, the demands of other treatment devices, and the desired water quality. Chapters 2 and 3 discuss recommended pretreatment and posttreatment procedures for individual devices, as appropriate.

Considerations When Choosing a Device

A variety of treatment options usually exists to safely resolve a water quality problem. The selection of a device or system should be based on a case-by-case technical evaluation and on an assessment of the economics involved. Choose the device with the best balance of the following criteria: high contaminant removal capacity, high flow rate capacity, few maintenance requirements, easy adaptability to the owner's lifestyle, few space considerations, and low cost. Keep in mind that most treatment devices do not eliminate a contaminant but only reduce the concentration to an acceptable level, which is usually defined by the U.S. Environmental Protection Agency (EPA) drinking water standards (see appendixes A and B).

When deciding between a POU or POE device, consider the nature of the contaminant in question. A POU device at the kitchen sink will not eliminate all potential exposure to volatile organic chemicals (VOCs) or radon. These chemicals, which are hazardous when inhaled, move from dispensed water into the surrounding air—especially through showers, dishwashers, or washing machines.

When to Test Treated Water

When treating contaminants that cause health effects, it is important to monitor a treatment device's performance by periodically testing treated water. Test water immediately after installation to assure that the unit is working properly. Subsequent, regular testing will ensure continued effectiveness.

Table 1.1
Approximate daily water needs for home and farm

Water use	Gallons of water used
Household drinking and cooking	1 per person per day
Bathing and showering	25 to 60 per bath or shower
Dishwashing	6 to 19 per load
Clothes washing	20 to 33 per load
Flushing toilets	25 to 30 per person per day
Lawn watering and other outside uses	30 per hour per 100 square feet of lawn
Hot water	25 per person per day
Livestock drinking water:	
Cattle	8 to 12 per day
Dairy cows	
Milking	18 to 25 per day or 40 per hundredweight
Dry	10 to 15 per day
Swine	
Sow	6 to 8 per day
Finishing	3 to 5 per day
Horses	12 per day
Sheep	2 per day
Chickens	
100 layers	9 per day
100 broilers	6 per day
100 turkeys	20 to 25 per day
Cleaning, milking equipment	300 to 450 per day per 100 milkers

If the contaminant concentration in the untreated water is sure to remain constant, relax the testing schedule after a period and define a maintenance routine based on the results of the testing schedule. Remain aware of conditions that may change the concentration of contaminants and affect the maintenance interval. Understanding contaminant sources will help determine if such a change may occur. For example, contaminants may wash into an unprotected water supply during flooding and increase certain contaminant concentrations.

As illustrated in figure 1.2, concentrations of contaminants that result from an improper land use such as mining or dumping vary as the contaminant plume moves through the aquifer. If the contaminant source is removed, the contaminant concentration eventually diminishes. Concentrations of naturally occurring contaminants in the aquifer may be more consistent.

When the contaminant has no distinct odor or taste, treatment may give a false sense of security, because breakthrough is not obvious. In such cases, test the water regularly or buy a unit with a warning device that indicates when the unit is malfunctioning. Always pay special attention to the manufacturer's maintenance instructions.

Equipment Maintenance Requirements

Water treatment equipment requires regular maintenance such as refilling chemical supplies, cleaning or changing components, and making various adjustments. Before purchasing any equipment, thoroughly examine all maintenance requirements. Many dealers offer maintenance contracts for those who are unable or unwilling to properly care for a treatment unit.

Maintenance contracts are sometimes a good idea, but they can also be unnecessary depending on the type of contaminant and unit in question. When dealing with health hazards or a complex maintenance procedure, a maintenance contract may be worthwhile. When treating only for nuisance contaminants or when the maintenance interval is long and the procedure simple, a contract may not be worth the extra cost.

Federal and State Regulations

The EPA does not test or approve home water treatment equipment, although an EPA registration number may appear on some devices. Such a number appears on treatment devices that use iodine and on activated car bon devices that contain silver, an element that limits bacterial growth. The EPA used to require that all devices containing silver be registered since silver was once an EPA primary drinking water contaminant. Devices using iodine must be registered because of concern about possible health effects. An EPA registration number does *not* mean that the EPA has evaluated or approved a device.

Few states currently regulate the water treatment industry; however, many states are considering implementing or strengthening requirements on the types of devices that manufacturers can sell, and on the selling techniques and promotional tools dealers can use. Unscrupulous dealers may use tactics designed to frighten people into purchasing equipment. Some even use misleading newspaper articles or misrepresent water test results, hoping to sell a treatment device that may be unnecessary. Many people contend that the water treatment industry can successfully police itself through trade organizations such as the Water Quality Association (WQA) and voluntary participation in programs that promote ethical sales guidelines.

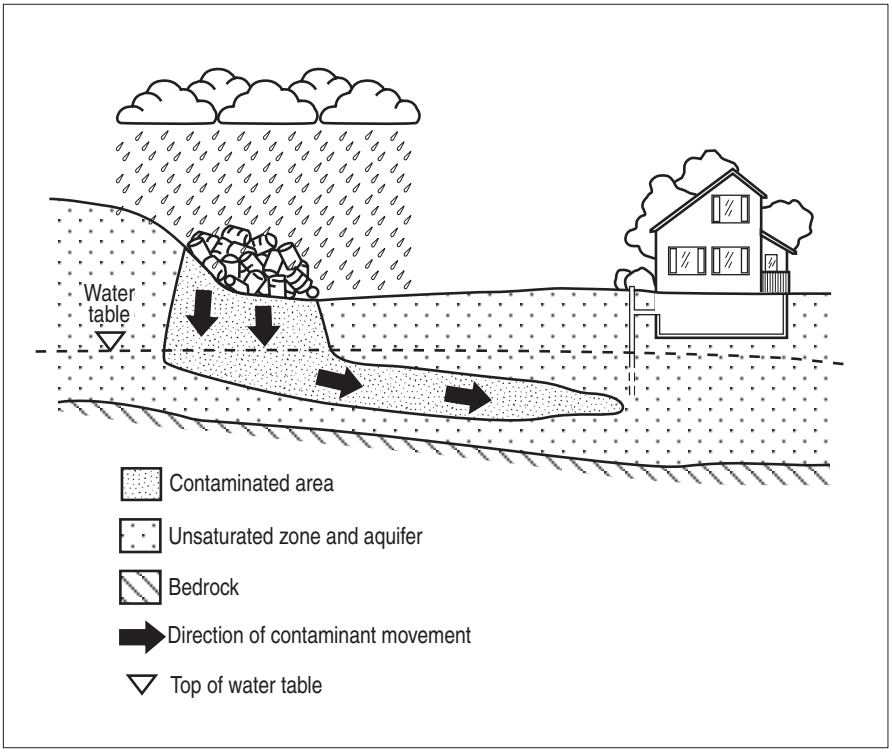

Figure 1.2
A plume of contaminated water moving through the aquifer.

The National Sanitation Foundation (NSF)

The National Sanitation Foundation (NSF) is a third-party, nonprofit organization that establishes performance standards for water treatment equipment. The standards define testing procedures and minimum requirements for evaluating the performance of water treatment units, as well as requirements for customer information and product labeling. The NSF currently has eight standards for drinking water treatment devices. They are listed in table 1.2.

Table 1.2
National Sanitation Foundation (NSF) standards for drinking water treatment

Standard number	Standard
42	Drinking Water Treatment Units—Aesthetic Effects
44	Cation Exchange Water Softeners
53	Drinking Water Treatment Units—Health Effects
55	Ultraviolet Microbiological Water Treatment Systems
58	Reverse Osmosis Drinking Water Treatment Systems
60	Drinking Water Treatment Chemicals—Health Effects
61	Drinking Water System Components—Health Effects
62	Drinking Water Distillation Systems

The NSF standards also include specifications for pressure drop, minimum service flow rates, materials, design, device construction, and overall performance. All products certified by the NSF have a data plate that states the minimum requirements of any applicable standards. The NSF also requires that a fact sheet be available to consumers who purchase NSF-certified units. The fact sheet must specify information such as the service flow rate, pressure drop, capacity, maximum and minimum operating pressures, maintenance requirements, warranty information, and the removal capacity for the contaminants covered by any applicable standards.

If a device is advertised as able to remove chemicals that cause adverse health effects, NSF standards require that the device have a means of alerting the owner of a malfunction. This may be accomplished by:

1. Having the unit stop discharging treated water.

2. Sounding an alarm or having a flashing light appear.

3. Providing an obvious, readily interpretable indication of malfunction, such as a 50 percent decrease in water flow.

4. Providing simple, explicit instructions for determining when maintenance is needed with a minimum 100 percent safety factor. For example, the manufacturer may provide a meter that measures gallons of water treated and recommend maintenance (such as cartridge replacement) when the treatment device has treated half of the total gallons it is capable of treating.

A device does not have to be certified by the NSF to adequately treat water as claimed by the manufacturer. Manufacturers must pay between $10,000 and $50,000 for NSF testing. If a device passes, the NSF certifies it and continues to monitor the manufacture and performance of the device. The opinions and findings of the NSF represent professional judgment based on laboratory evaluation.

Physical vs. Chemical Treatment

In this publication, water treatment is divided into physical and chemical procedures. Physical treatment, discussed in chapter 2, removes contaminants from water without adding chemicals or minerals. The owner is not required to stock and refill chemicals, but these systems may reduce water pressure, consume lots of energy, or require waste disposal or frequent cleaning. Chemical treatment, discussed in chapter 3, changes, removes, or inactivates a contaminant through the addition of a solid, liquid, or gas to the water. In general, chemical treatment systems treat all water entering the house,correct a wide variety of water quality problems, and do not require electricity. The disadvantages of chemical treatment methods include having to stock and refill chemicals, dealing with safety hazards associated with chemical handling, maintaining injection equipment, or adding an undesirable taste or odor to the treated water.

The selection of individual or combinations of technologies to reduce contaminant levels should be based on a case-by-case technical evaluation, and on an assessment of the economics involved. Water test results can be used with information in the water treatment key (table 1.3 on page 8) and appendixes A and B to identify potential treatment technologies.

Before purchasing any water treatment device or system, consider whether water treatment is needed at all. If the water quality problem does not present a health hazard, it may make more sense to simply live with the problem or buy bottled water for drinking and cooking.

Table 1.3
Water treatment key

Water treatment device or method [a]	Problems addressed by the water treatment method	Point-of-Use (POU) or Point-of-Entry (POE)
Physical treatment		
Cartridge sediment filter	Turbidity, particles, and sediment; oxidized iron, manganese, and hydrogen sulfide. Some may remove *Giardia lamblia* and *Cryptosporidium parvum*.	POU or POE
Media filter	Turbidity, particles, and sediment; oxidized iron, manganese, and hydrogen sulfide.	POE
Multimedia filter	Turbidity, particles, and sediment; oxidized iron, manganese, and hydrogen sulfide.	POE
Precoat filter	Turbidity, particles, and sediment; oxidized iron, manganese, and hydrogen sulfide. Some may remove asbestos, *Giardia lamblia,* and *Cryptosporidium parvum*.	POE
Reverse osmosis	Most inorganic components of total dissolved solids (TDS), including nitrate and lead. May remove some organic chemicals.	POU
Activated carbon	Tastes and odors; chlorine and iodine residuals; radon gas; certain organic chemicals, including some volatiles, pesticides, and trihalomethanes (THMs). May be designed for lead removal.	POU or POE
Activated alumina	Fluoride,[b] arsenic, selenium, and chromium.	POU or POE
Boiling	Coliform bacteria, *Giardia lamblia* and *Cryptosporidium parvum*, some volatile organic chemicals (VOCs).	POU
Distillation	Coliform bacteria, *Giardia lamblia* and *Cryptosporidium parvum*, most metals and inorganic chemicals, some organic chemicals and pesticides, total dissolved solids (TDS).	POU
Ultraviolet light	Viruses and coliform bacteria if coliform levels do not exceed 1,000 total coliforms per 100 milliliters or 100 fecal coliforms per 100 milliliters.	POU or POE
Chemical treatment		
Neutralizing filter	Corrosive water due to low pH (acidity).	POE
Soda ash/sodium hydroxide injection	Corrosive water due to low pH (acidity).	POE
Acid injection	Corrosive water and “soda” taste due to high pH (alkalinity).	POE
Water softening (cation exchange)	Hardness (calcium and magnesium), barium, radium, and small amounts of dissolved iron and manganese.	POE
Anion exchange	Nitrate, sulfate, and arsenic.	POU or POE
Chlorination	Certain viruses and bacteria; dissolved iron, manganese, and hydrogen sulfide;[c] iron, manganese, and sulfur bacteria.	POU or POE
Potassium permanganate	Dissolved iron, manganese, and hydrogen sulfide; iron bacteria.	POE
Oxidizing filter	Dissolved iron, manganese, and hydrogen sulfide.	POE
Iodination [d]	Bacteria, some viruses.	POU or POE
Phosphates [e]	Hardness (calcium and magnesium), small amounts of dissolved iron.	POE
Aeration	Volatile organic chemicals (VOCs), radon, other dissolved gases.	POE
Ozonation	Certain viruses and bacteria, *Giardia lamblia* cysts, and other microorganisms; dissolved iron, manganese, and hydrogen sulfide;[c] some metals; color, odor, and many tastes.	POE

[a] The recommendations in this table are general. Water pH, total dissolved solids (TDS), other particulate substances, or other water quality or water distribution system factors may affect the effectiveness of a treatment device. Before purchasing a device, be sure to investigate its limitations. For more information about potential treatment technologies available to remove a specific contaminant, see appendixes A and B.

[b] Fluoride concentrations in the range of 1 milligram per liter are desirable in drinking water for protection against tooth decay. For this reason, fluoride may be added to a municipal water supply. Fluoride concentrations greater than 2 milligrams per liter may have negative effects (see appendix A, table A.1, and appendix B, table B.1).

[c] This treatment method oxidizes dissolved iron, manganese, and hydrogen sulfide. The resulting particles must be removed with a mechanical postfilter.

[d] The U.S. Environmental Protection Agency approves iodination only for emergency or temporary use due to possible health effects. Nevertheless, some states allow routine iodine disinfection. Consult local regulations for more information.

[e] Phosphates are not allowed in some states. Consult local regulations for more information.

2 Physical Treatment

Five types of systems treat water without chemicals: filtration, reverse osmosis, adsorption, heating, and ultraviolet light. During filtration and adsorption, untreated water passes through the treatment device and contaminants are retained in the device. Reverse osmosis units have a membrane that separates contaminants from water; contaminants are then sent to waste. Heating systems boil water to kill microorganisms, vaporize volatile organic chemicals (VOCs), or separate contaminants from water. Ultraviolet light damages the genetic material of microorganisms, preventing cell replication and effectively killing the microorganisms.

Mechanical Filtration

Mechanical filtration systems include cartridge sediment filters, media and multimedia filters, and precoat filters. They are used most often in home water treatment to remove sediment or iron, manganese, or sulfur particles.

In mechanical filtration systems, water passes through a medium such as cloth or sand. Particles become trapped on the surface of or within the medium. The pore size, or space between media granules or fibers, determines what size particles a filter can retain. The pore size varies around an average value that depends on the manufacturing method.

Filters are rated according to the smallest particle they can trap. Particles are measured in microns. (One micron is equal to one thousandth of a millimeter or four hundred thousandths of an inch.) For example, a 5-micron filter would remove particles that are 5 microns or larger. Some filters have a wide variety of pore sizes and are nonspecific to the size particle they allow through. Figure 2.1 on the following page shows the range of particle sizes filterable by various mechanical filtration processes and reverse osmosis, which is discussed beginning on page 19. It also indicates the relative sizes of common water contaminants.

The required rate of water flow through a device depends on the intended use—as a point-of-use (POU) device on a single faucet or as a point-of-entry (POE) device for the whole house. The flow rate also depends on the surface area and pore size of the filter medium, the water pressure, and the suspended solids concentration in the untreated water. The surface area is the amount of filter medium in contact with the untreated water. For all of the devices discussed in this publication, surface area is measured in square feet. The larger the surface area, the greater the potential flow rate through the filter. The potential flow rate decreases as pore size decreases.

Each of the filter types discussed in this section is a pressure filter. Water enters the filter under pressure and leaves at a reduced pressure due to pressure loss in the filter. If the incoming water pressure is insufficient, a booster pump can help achieve an

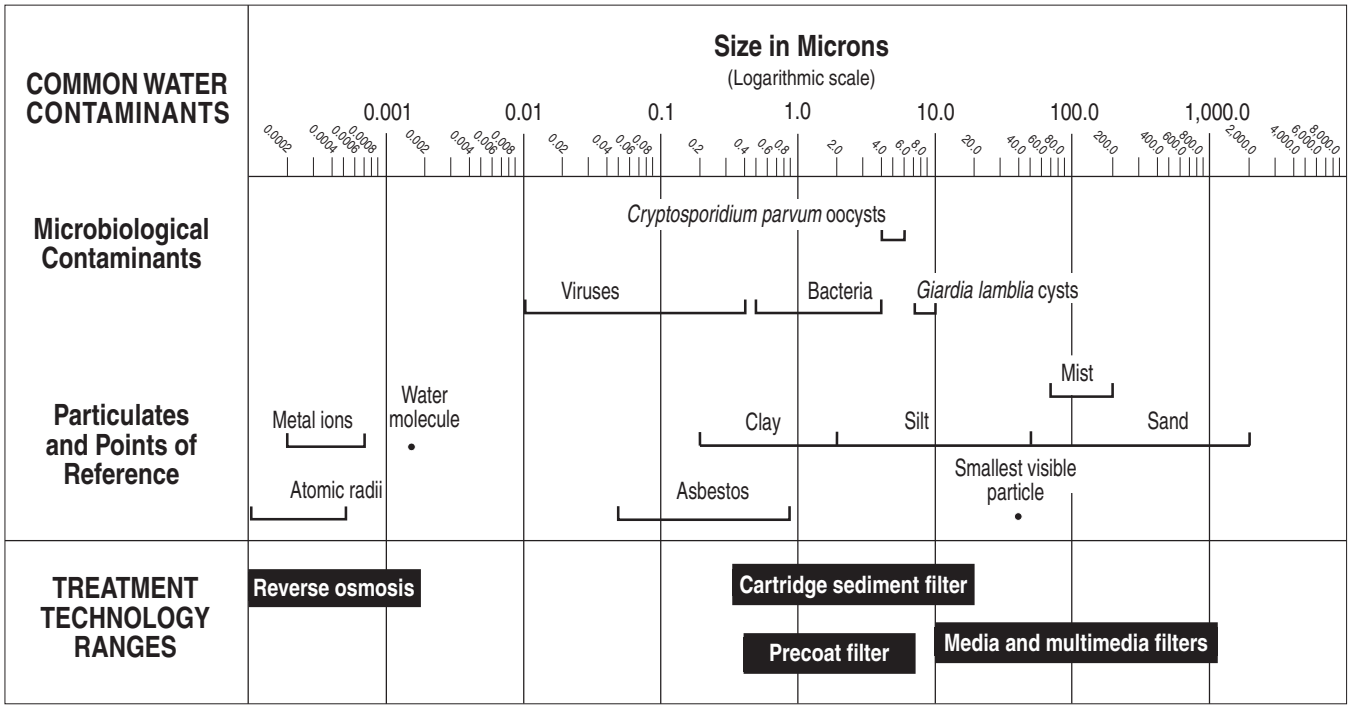

Figure 2.1
The filtration spectrum.

Source: Adapted courtesy of Osmonics, Inc., Minnetonka, Minnesota ©1993.

Notes: (1) 1 micron = 0.001 millimeter or 0.00003937 inch (2) Definitions of sand, silt, and clay particles are based on U.S. Department of Agriculture classifications. (3) The width (smallest dimension) of *Giardia lamblia* cysts ranges from 7 to 10 microns. The width (smallest dimension) of *Cryptosporidium parvum* oocysts ranges from 4 to 6 microns. (4) Media, multimedia, cartridge, and precoat filters are rated based on the smallest particles they remove. The ranges given in this figure refer to the range of particle size ratings. (5) Media and multimedia filters are not recommended for waterborne bacteria, viruses, or protozoan cysts such as *Giardia lamblia* and *Cryptosporidium parvum*. Cartridge sediment filters that are rated to remove particles 1 micron in diameter or greater may be used to remove *Giardia lamblia* cysts or *Cryptosporidium parvum* oocysts. Precoat filters are not recommended for bacteria or viruses, but they can be designed to remove *Giardia lamblia* and *Cryptosporidium parvum*. Consult a water treatment professional for more information.

acceptable flow rate. Normal household water pressure ranges from 30 to 60 pounds per square inch. The pressure may be supplied by a municipal water system, a water pump, or gravity (for more explanation, see figure 1.1, page 4).

Which filtration method to select depends on the concentration and size of suspended solids in the source water and the rate at which water needs to be treated. Media filters such as sand filters have a greater contaminant removal capacity than other types of filtration devices. However, cartridge filters with fiber or ceramic filter material are made with a smaller and more uniform pore size and can be more reliable in removing small particles.

This section discusses options for filtration devices that are installed in the home. For surface water sources such as ponds, slow-sand filtration is recommended as pretreatment. Slow-sand filtration is different from sand media filtration.

Surface waters have higher concentrations of suspended solids than groundwater or protected springs. They may even contain large particles such as leaves and algae. Slow-sand filters have a greater capacity for filtering these larger solids than the sand filters discussed in this publication. For more information on how to design, construct, operate, and maintain a slow-sand filter, see *Private Water Systems Handbook,* MWPS–14.

Cartridge Sediment Filters

Cartridge sediment filters remove only suspended solids. Manufacturers rate them according to the size of particles they remove. Some activated carbon devices are also rated by the size of particles they remove, but it is uneconomical to use activated carbon for particle filtration.

Cartridge filters have a housing, usually made of plastic, and a filter made of paper, cellulose, polypropylene, cloth, ceramic, or string. The filter material is often wound or corrugated to provide the maximum surface area for filtration. A typical filter housing and several cartridge filters are shown in figure 2.2.

Uses

Cartridge filters can be either point of-use (POU) or point-of-entry (POE). They remove particles that cause turbidity; are one step in removing iron, manganese, and hydrogen sulfide; and prefilter water to protect other treatment devices. Dissolved iron, manganese, or hydrogen sulfide must be oxidized into solid particles via chlorination or ozonation before they can be removed by a cartridge filter. These processes are described in more detail in chapter 3.

Cartridge filters are used as prefilters when suspended solids in the untreated water could reduce the effectiveness or service life of the primary treatment device. For example, consider untreated water that contains suspended solids and an organic chemical removable with activated carbon. If an activated carbon device were used to remove the organic chemical and the suspended solids were not removed first, the suspended solids would clog the activated carbon unit, thus reducing its service life. Therefore, a cartridge filter or other mechanical filter should precede the activated carbon device to remove the suspended solids.

Manufacturers rate cartridge filters according to the particle sizes they remove. As indicated in figure 2.1, cartridge filters can remove particles as small as 0.35 micron in diameter. It is important to check the filter rating before purchasing a device, since some filters are rated only for particles larger than 20 microns.

Generally, cartridge sediment filters are not recommended for removing microbiological contamination. However, protozoa such as *Giardia lamblia* and *Cryptosporidium parvum* resist conventional disinfection methods, and filtration may be the only option for removing them. These microorganisms are more likely to occur in surface water supplies such as springs, ponds, or streams than in groundwater. To remove microorganisms such as *Giardia lamblia* and *Cryptosporidium parvum,* choose a filter material that has a uniform pore size and is rated to remove particles 1 micron in diameter or greater. A poorly designed filter may allow untreated water to bypass the filter material. Alternate methods for removing protozoa include precoat filtration (see page 18), boiling (see page 32), and distillation (see page 33).

Cartridge sediment filters are not recommended for removing organic chemicals. Activated carbon devices can remove certain organic chemicals. They are discussed in more detail beginning on page 26. Some manufacturers combine activated carbon with

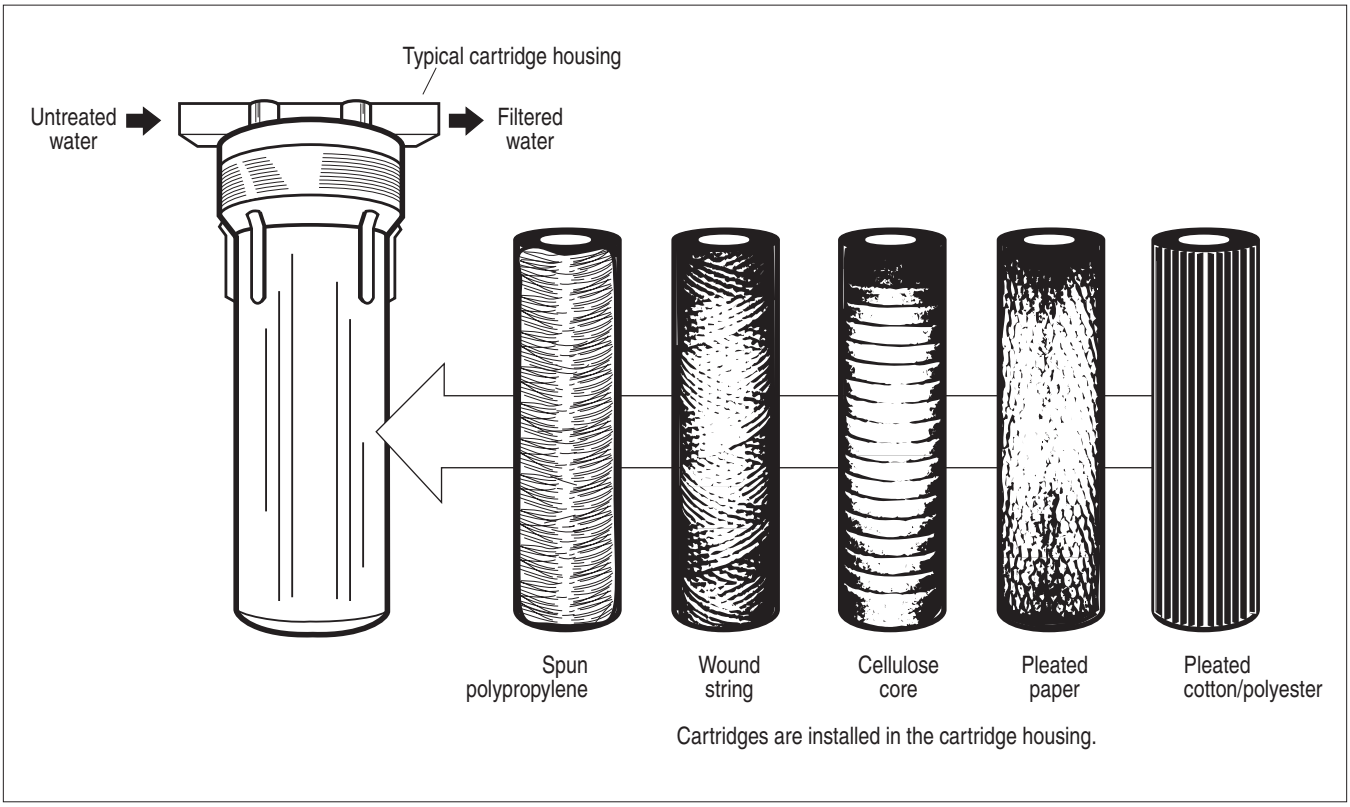

Figure 2.2
Various cartridge filters used in a cartridge sediment filter.
Adapted with permission from *Water Technology* magazine.

the filter material in a cartridge sediment filter, in which case the cartridge filter should remove both suspended solids and certain organic chemicals. For information on other possible methods for removing organic chemicals, see the water treatment key (table 1.3 on page 8) and appendix A.

Principles

During filter operation, untreated water flows through the cartridge and suspended solids are retained on the filter material surface. Water flows from the outside of the cartridge to the cartridge core. If the pore size of the filter material is too small, or if the concentration of suspended solids in the untreated water is too high, the filter will become clogged easily and require frequent replacement. If the pore size is too large, suspended solids may pass through the device. Cartridge filter operation is illustrated in figure 2.3.

The maximum water flow through a cartridge filter occurs after a new or replacement cartridge is first installed. As suspended solids accumulate in the filter, they assist in the filtration process, and the filter's effectiveness increases. Water flow, however, gradually decreases. When water flow is no longer acceptable, the cartridge or filter material should be replaced.

Types

The two basic types of cartridge filters are depth-type and pleated. Both are illustrated in figure 2.4. The depth-type filter has a $^{3}/_{4}$- to $^{7}/_{8}$-inch-thick porous wall and is made of cotton, spun polypropylene, or resin-bonded cellulose. Some depth-type filters need a center polypropylene core for support. Certain manufacturers offer filters that have graded densities—openings are large at the outermost surface of the filter and decrease in size toward the center core. For these filters, some particles are trapped within the filter material instead of on the surface. Depth cartridges are usually inexpensive.

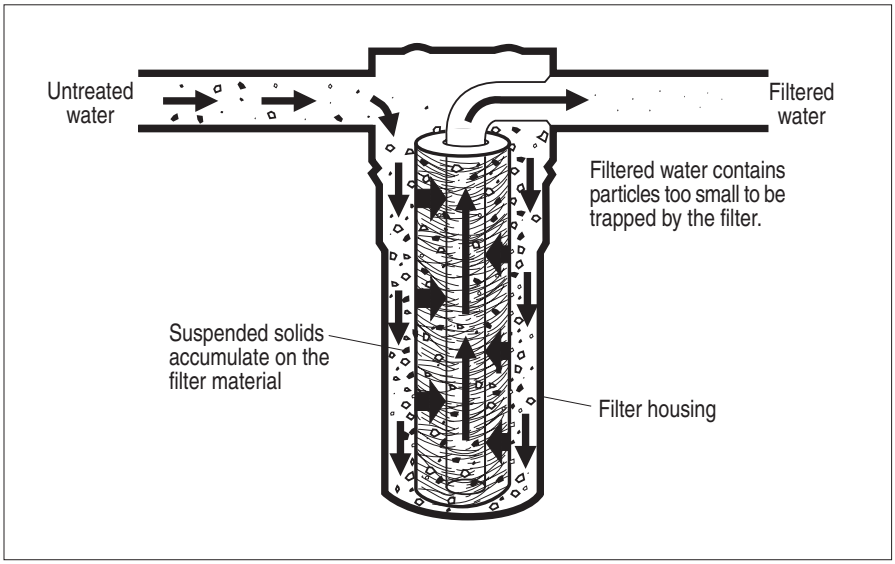

Figure 2.3
Cartridge filter operation.

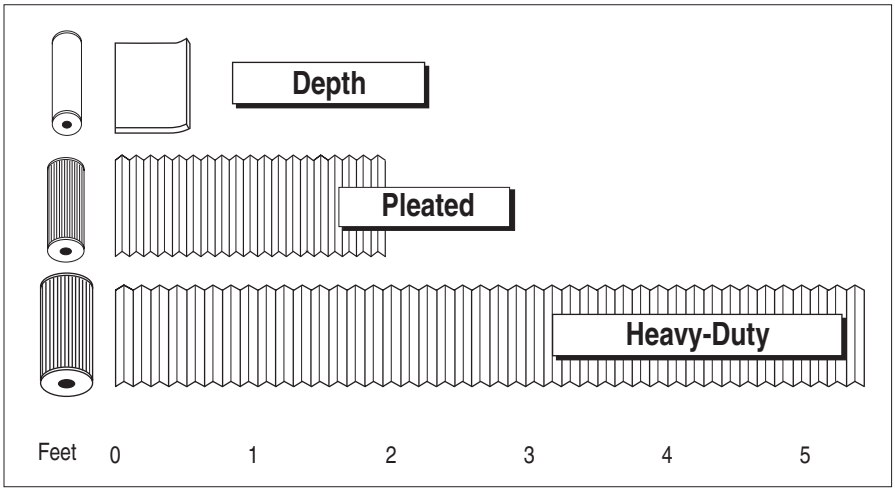

Figure 2.4
Depth versus pleated cartridge filters.
Adapted with permission from *Water Technology* magazine.

The second type of cartridge filter is the pleated type. The pleats increase the flow rate capacity by providing a greater surface area for filtration. The filter wall ranges from $^{1}/_{32}$ to $^{3}/_{32}$ inch thick. The filter accumulates particles on the outermost surface, allowing a filter cake to build up and thus increasing the filtering action. Water flow usually slows as the filter cake develops. Heavy-duty pleated filters have an increased surface area to further improve flow rate and filtering capacity.

Most pleated filters can be rinsed in the sink or with a garden hose and reused several times. They handle large quantities of turbidity before water pressure drops noticeably. Although they initially cost more than other cartridge types, in the long run they are less expensive.

Pleated cartridge filters contain a rigid polypropylene core for support and are made of one of the following materials:

- Pleated paper. These filters are the most economical but are not reusable. They are sensitive to water with a low or high pH (less than 6.5 or greater than 8.5). Use them only when the water contains no active bacteria, which feed on the cellulose portion of the filter.

- Pleated cotton/polyester. These filters are generally considered to be the most versatile because they combine the filtration ability of cotton with the strength of polyester. If the water pH is between 4 and 9, they can be cleaned and reused several times.

- Pleated polyester and polypropylene. These filters are the most expensive but can be rinsed repeatedly and reused. Since the fibers are rather smooth, they are not as effective in retaining particles as cotton/polyester filters. In fact, unloading can be a problem with these filters.

Capacity

Base the selection of a particular cartridge filter on the flow rate produced at household water pressure, the amount of water treated before maintenance is required, and the desired water quality. Flow through the filter depends on the water pressure and characteristics of the filter material and source water.

The manufacturer should be able to provide information concerning the initial flow rate through the device at a specific pressure. The initial flow rate is the water flow immediately after installing a new or replacement cartridge, before particles accumulate on the filter. This flow gradually decreases as suspended solids accumulate. The National Sanitation Foundation (NSF) suggests a minimum initial service flow rate of 4 gallons per minute for POE units, 0.5 gallon per minute for in-line POU units, 2 gallons per day for line-bypass POU units with a storage tank, and 0.2 gallon per minute for line-bypass POU units without a storage tank. (All flow rates are at 30 pounds per square inch—typical household water pressure). Other sources suggest a minimum flow rate of 7 to 10 gallons per minute for POE units and 1 gallon per minute for POU units.

When investigating the service flow rate of any particular device, note the water pressure required to achieve the flow rate advertised by the manufacturer. If the filter will be used to pretreat water, the primary treatment device will determine the required capacity.

Maintenance

Replace or clean the cartridge when there is a noticeable drop in water flow through the device—usually after several weeks or months of use. Some cartridges are rated according to the number of gallons they can treat. While these ratings provide a guideline for maintenance, variations in the nature and quantity of suspended solids make it difficult to accurately predict the time between cartridge replacements.

If the cartridge requires replacement too often, a media filter may be more economical. Media filters effectively treat water containing particles greater than 10 microns in diameter. Use the equations below to compare the annual cost of a cartridge filter with the cost of a media filter. Costs vary, so check with a local water treatment dealer for current prices and a more accurate calculation.

$$\text{annual cost of a media filter} = \frac{\text{purchase price}}{\text{expected operating life in years}}$$

$$\text{annual cost of a cartridge filter} = \frac{\text{purchase price x 12}}{\text{months between changes}}$$

Example:

$$\text{annual cost of a media filter} = \frac{\$700}{10 \text{ years}} = \$70 \text{ per year}$$

$$\text{annual cost of a cartridge filter} = \frac{\$50 \times 12}{6 \text{ months}} = \$100 \text{ per year}$$

Special Considerations

Plastic housings for cartridge sediment filters generally look the same. The filter material differentiates one device from another. The same plastic housing used for cartridge filters may be used to enclose activated carbon or reverse osmosis membranes. Be sure to examine filter information completely to ensure purchasing the correct device.

Media Filters

Media filters consist of a tank, a filter medium, a support system, and an underdrain. The filter medium is usually 24 to 36 inches deep and can be silica sand, aluminum silicate, or anthracite. The tank encloses the filter medium; the support system, usually gravel, prevents the medium from being washed out of the device.

Water enters the filter tank through the top and percolates through the medium, which traps any suspended solids. Treated water exits the device via the underdrain. Unlike some cartridge sediment filters, media filters can be cleaned and reused.

It is important to note that sand filters discussed in this section are pressure filters, not slow-sand filters. See *Private Water Systems Handbook,* MWPS–14, for information on slow-sand filtration.

Uses

Media filters are point-of-entry (POE) devices. They remove partcles that cause turbidity and are one step in removing iron, manganese, and hydrogen sulfide. Dissolved iron, man-

ganese, and hydrogen sulfide must be oxidized into solid particles via chlorination or ozonation before they can be removed by a media filter. These treatment methods are further described in chapter 3.

Media filters are used as prefilters when suspended solids in the source water could reduce the effectiveness or service life of the primary treatment device. For example, an ultraviolet (UV) light device disinfects water. If suspended solids are not removed prior to the UV device, the solids may shield microorganisms from the light and result in incomplete treatment.

Filters are rated by the smallest particle sizes they remove. As indicated in figure 2.1 on page 10, media filters should not be used for removing suspended solids smaller than 10 microns in diameter. They are also ineffective in removing microbiological contaminants and organic chemicals.

Principles

Water enters the filter under pressure and passes through the medium, which retains suspended solids. Treated water exits the filter at a slightly reduced pressure. Figure 2.5 illustrates this process.

As suspended solids accumulate on the media surface, they help filter fine particles but gradually increase resistance to water flow. If not correctly maintained, the filter will provide increasingly less treated water.

The media particle size affects the size of suspended solids that can be removed from the water—the smaller the media, the smaller the particles that can be removed. However, water flow through the unit also decreases as the media particle size decreases.

Capacity

The filter tank's diameter determines a media filter's flow rate capacity—the greater the diameter, the greater the flow. The flow rate is also affected by the media particle size and the suspended solids concentration in the water.

Table 2.1 gives approximate service flow rates per square foot of media surface area for different types of media. To calculate the media surface area, measure the diameter of the media column in inches. Divide this diameter by twenty-four, square the resulting number, and then multiply by 3.14.

$$\text{media surface area in square feet} = \left[\frac{8 \text{ inches}}{24}\right]^2 \times 3.14$$

For example, for an 8-inch-diameter media filter, the surface area would be:

Example:

$$\text{media surface area in square feet} = \left[\frac{8 \text{ inches}}{24}\right]^2 \times 3.14 = 0.35 \text{ square feet}$$

Based on the service flow rates in table 2.1 for a silica sand media filter, the flow rate for a media filter with a surface area of 0.35 square foot would vary from 0.35 gallon per minute to 1.4 gallons per minute, depending on the suspended solids concentration in the water. The backwashing requirement would vary from 4.2 gallons per minute to 5.2 gallons per minute.

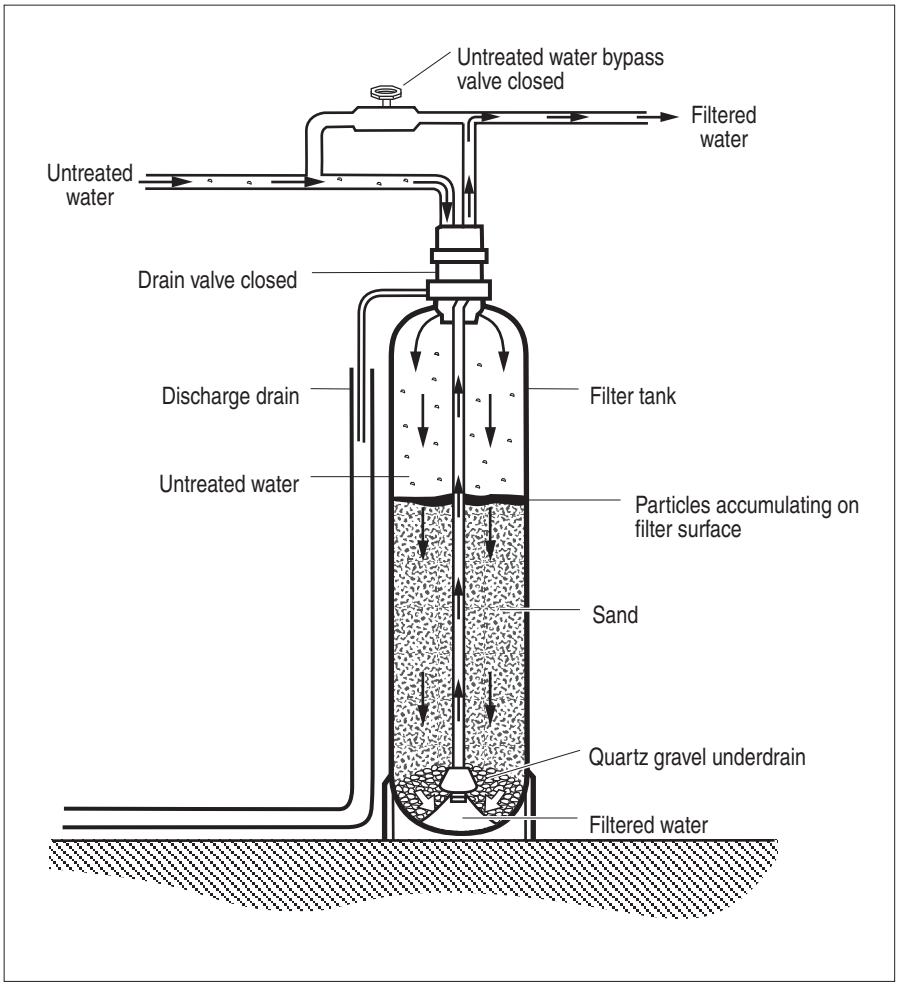

Figure 2.5
Media filter components and operation.

Table 2.1
Characteristics of some filter media used in media filters

Media	Typical particle size (microns)	Service flow rate (gallons/minute/ square foot)	Backwashing (gallons/minute/ square foot)	Bed depth (inches)
Silica sand	500	1 to 4	12 to 15	24 to 36
Aluminum silicate	600	5	8 to 10	24 to 36
Anthracite	700	1 to 2	8 to 10	24 to 30

Source: Adapted with permission from *Water Technology* magazine.

If the backwashing flow rate from the well, spring, or other water source limits the filter size to one with an unacceptable flow rate capacity, use multiple, smaller filter tanks as illustrated in figure 2.6. Using manufacturers' data for various filter sizes, determine the tank diameter that can be backwashed with the available flow rate. Then, to determine the number of tanks needed, divide the desired flow rate by the maximum service flow for the chosen tank diameter.

When using two tanks, it is important to backwash each tank individually since all the available flow is needed to achieve the required backwash rate of a single tank. For example, consider a sand tank for which the available flow rate is 6.5 gallons per minute. According to table 2.2, if the desired yield is 4.4 gallons per minute, use two 10-inch tanks in parallel (as shown in figure 2.6) and backwash them individually. This yields a treated water flow of 4.4 gallons per minute, and the 6.5 gallon-per-minute flow rate should be sufficient for backwashing.

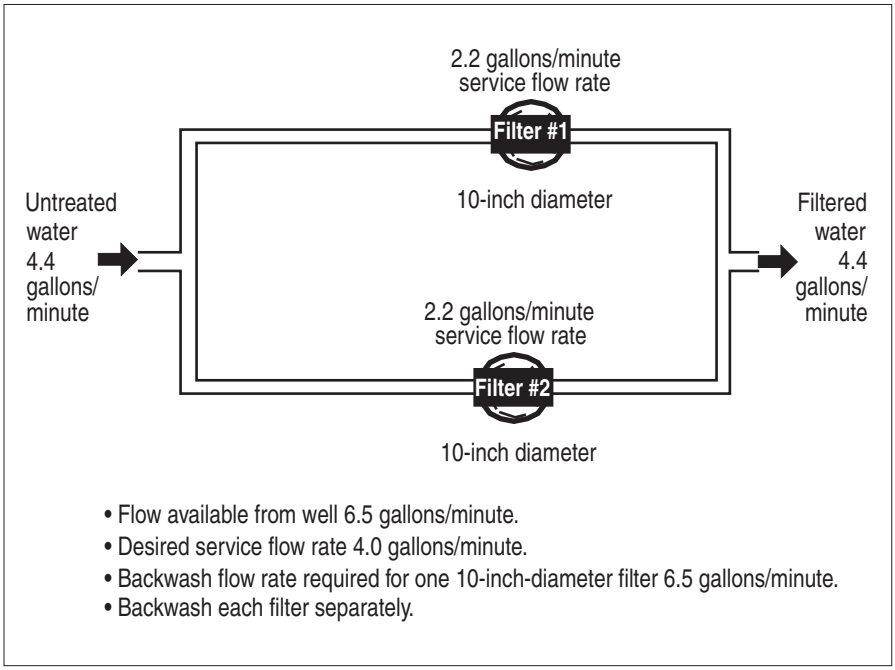

Figure 2.6
Using two media filters to overcome inadequate backwash flow rate.

Table 2.2
Sample data for sand filters

Tank diameter (inches)	Maximum service flow (gallons/minute) [a]	Minimum backwash flow (gallons/minute) [b]
8	1.4	4.2 to 5.2
9	1.8	5.3 to 6.6
10	2.2	6.5 to 8.2
12	3.1	9.4 to 11.8
13	4.6	11.1 to 13.8
14	5.4	12.8 to 16

[a] Service flow rates are greater for multimedia filters with the same tank diameter.

[b] Backwash flow rate requirements are similar for multimedia filters with the same tank diameter.

Maintenance

Media filters should be backwashed on a regular basis to prevent accumulated particles from clogging the device. Backwashing reverses the direction of water flow through the filter by forcing water into the bottom of the filter tank and out through the top. As

is illustrated in figure 2.7, this flow expands the media bed and washes collected suspended solids out of the filter. Backwash a media filter at the manufacturer's recommended rate for ten to fifteen minutes. Backwash manual systems once a week. Automatic filters may be set to backwash daily.

Every filter has a water flow rate requirement for backwashing that is recommended by the manufacturer. Rates are usually two to five times the service flow rate. For homes with an inadequate flow rate, some venders provide a backwashing service.

Table 2.1 on the previous page lists some approximate backwash water flow rates per square foot of surface area for different media. A formula for calculating the surface area of filter media is given on page 14.

Special Considerations

It is important to minimize the add itional hydraulic waste load backwash water puts on a septic system. To illustrate why, consider a 12-inch-diameter sand filter that requires a backwash rate of between 9 and 12 gallons per minute. Backwashing daily for ten minutes at 9 gallons per minute would add 90 gallons to the septic sytem each day, along with the suspended solids washed from the filter. Manufacturer's recommendations for backwashing rates, times,and frequencies can help estimate the increased load backwashing would exert on a particular septic system. It is also important to consider the nature of the contaminants being removed by backwashing and their proper disposal.

Certain arid regions of the United States are considering banning backwashing because it increases water consumption. Before purchasing equipment that requires backwashing, consult a local health department or cooperative extension office for information on any local restrictions.

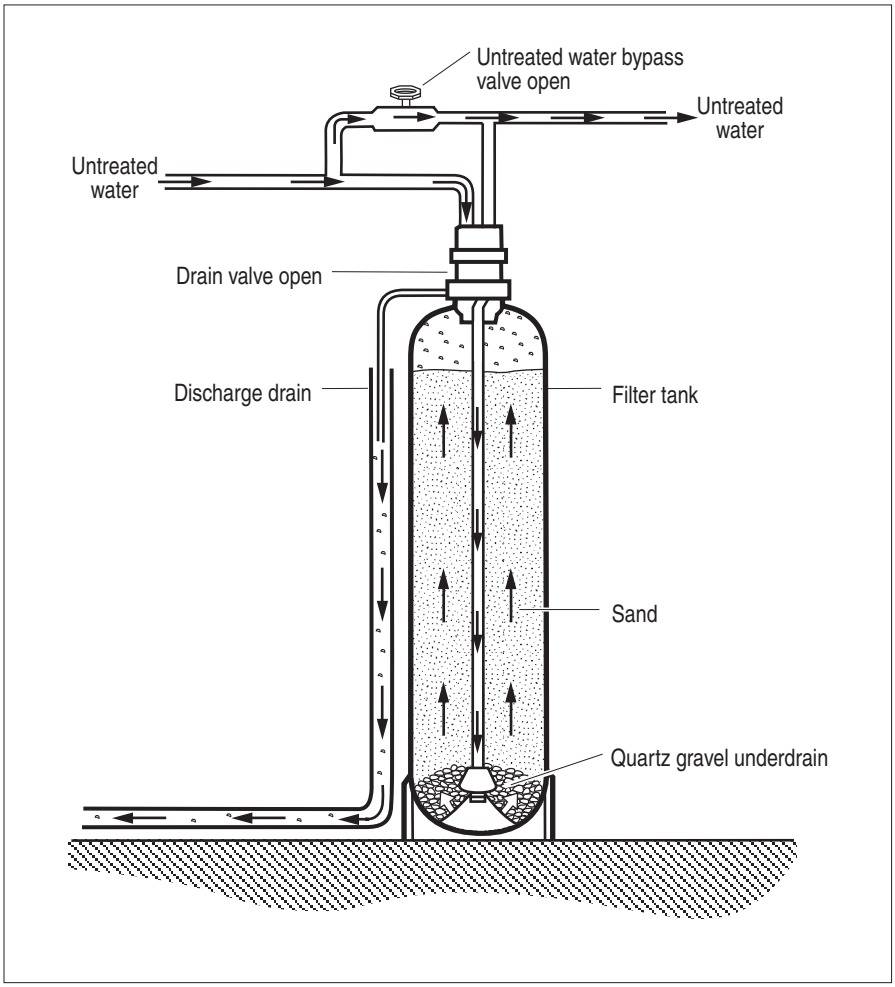

Figure 2.7
Backwashing a media filter.

Multimedia Filters

Multimedia filters have the same basic construction as media filters except the filter tank encloses three or four layers of different media. The filter media can be backwashed and reused. A multimedia filter has a greater filtering capacity than a single-media filter with the same tank diameter. Multimedia filters also operate at a higher flow rate and longer maintenance interval than single-media filters, so operating expenses tend to be less.

Uses

Multimedia filters are point-of-entry (POE) devices. They remove particles that cause turbidity and are one step in removing iron, manganese, and hydrogen sulfide. Dissolved iron, manganese, and hydrogen sulfide must be oxidized into solid particles via chlorination or ozonation before they can be removed by a multimedia filter. These chemical treatment methods are further described in chapter 3.

Multimedia filters are rated according to the size of particles they remove. In general, they are ineffective in removing particles smaller than 10 microns in diameter; bacteria, viruses, and cysts; and organic chemicals.

Provided that it has an appropriate density and particle size, activated carbon can replace the sand layer in a multimedia filter. Activated carbon removes tastes, odors, and some organic

chemicals. For more information on its uses in water treatment, see the section on activated carbon devices later in this chapter on page 26.

Multimedia filters are sometimes used as pretreatment devices to remove suspended solids in the source water that might reduce the effectiveness or service life of the primary treatment device. For example, a multimedia filter may be used to remove suspended solids from hard water before the water enters a POE water softener. If the suspended solids are not removed prior to softening, they may clog the water softener and shorten the device's maintenance interval.

Principles

In a multimedia filter, the coarsest media layer is on top. Each successively lower layer is finer. One example of layering in a multimedia filter is bituminous coal or plastic beads on top followed by layers of anthracite coal, sand, and garnet. The total media depth is approximately 48 inches. A media support system and an underdrain are located beneath the media bed. The media support system is usually gravel and prevents the media from washing into the underdrain.

Multimedia filter operation is illustrated in figure 2.8. Water enters the top of the tank under pressure and flows through the media layers. Suspended solids pass through the top layer and are trapped by lower layers.

Single-media filters, described in the previous section, retain particles on the top of the media column. In multimedia filters, the entire depth of the media column traps particles, thereby allowing a longer maintenance interval. This also increases the flow rate to 6 to 8 gallons per minute per square foot of surface area, which is greater than the flow rates for single media filters listed in table 2.1 on page 15.

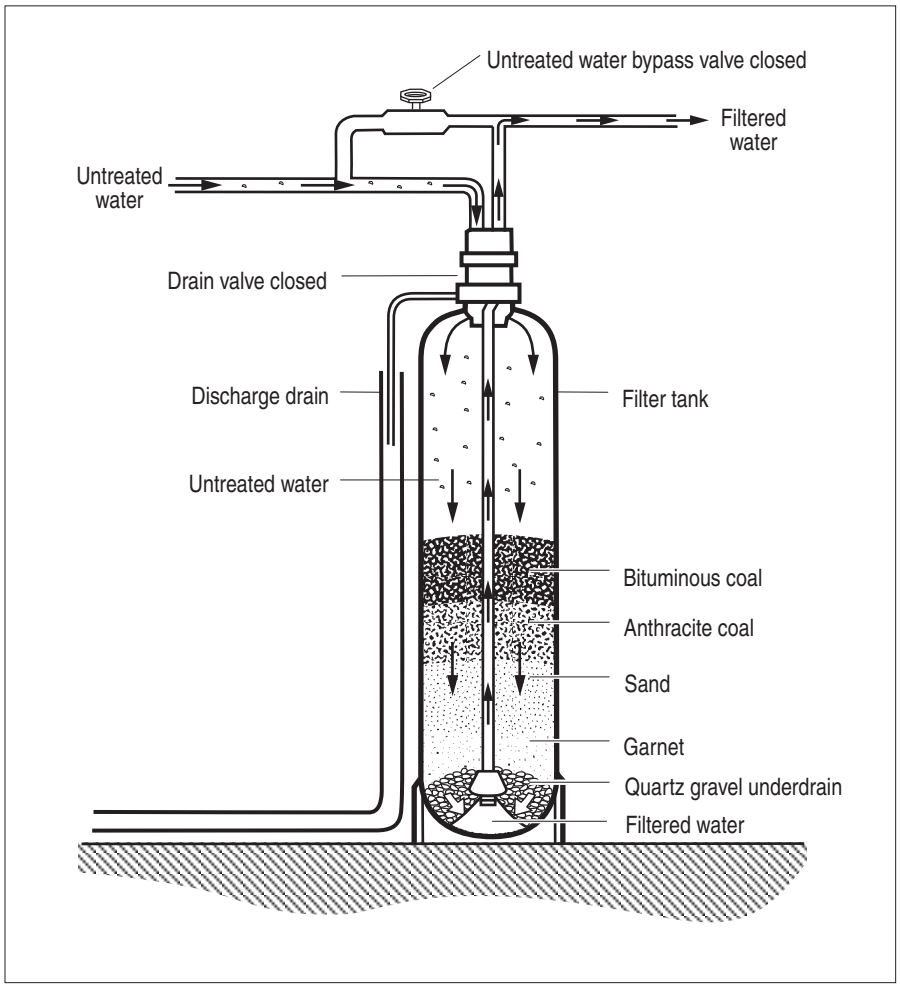

Figure 2.8
Multimedia filter operation.

The particle sizes of the media layers determine what sizes of suspended solids the filter can remove. If some of the suspended solids are too large to pass through the top layer, a filter cake may form on the media surface, preventing solids from infiltrating the lower media layers. As a result, the unit would behave more like a single-media filter, and the filter's contaminant removal capacity would be diminished.

Capacity

The filter tank diameter, media types, and media bed depth determine the service flow rate. In general, the greater the tank diameter, the greater the service flow rate. The water flow rate available for backwashing limits the tank size unless a water treatment equipment dealer provides a backwashing service. Manufacturers or water treatment equipment dealers can provide information concerning flow rates for various-diameter multimedia filters. Select the maximum tank diameter appropriate for the available backwash rate.

As with single-media filters, if the available backwash flow rate limits the size of the filter, use additional tanks. Each filter is backwashed separately since all the available flow is necessary to achieve the backwash flow rate of a single device. To determine the number of tanks needed, divide the desired flow rate by the flow rate for the

chosen tank diameter. For more information, review the previous discussion on page 15 about using two single-media filter tanks.

Maintenance

To maintain a consistent quantity and quality of treated water, backwash the filter media regularly. Backwashing reverses the water flow through the device, suspending media particles and carrying away any accumulated solids.

The physical characteristics of the filter media allow the layers to resettle in their proper order after backwashing. Although the upper layers are coarser, they are not as dense as the lower layers. For example, plastic beads in the top layer may be larger than a garnet grain, but they do not sink in water as fast. As a result, the finer garnet particles settle faster than the coarser plastic beads.

Multimedia filters can fail because of an inadequate backwash flow rate, an irregular backwashing schedule, or insufficient time allowed for backwashing. If backwashing is done improperly, untreated water may eventually channel through the media, resulting in a clogged underdrain or incomplete treatment. For households with an inadequate backwash flow rate, some water treatment equipment dealers offer a backwashing service.

Special Considerations

As with media filters, it is important to minimize the additional hydraulic waste load backwash water puts on a septic system. To illustrate why, consider a 12-inch-diameter multimedia filter that requires a backwash rate of between 9 and 12 gallons per minute. Backwashing daily for ten minutes at 9 gallons per minute would add 90 gallons to the septic system each day, along with the suspended solids washed from the filter. Manufacturer's recommendations for backwashing rates, times, and frequencies can help estimate the increased load backwashing would exert on a particular septic system. It is also important to consider the nature of the contaminants being removed by backwashing and their proper disposal.

Certain arid regions of the United States are considering banning backwashing because it increases water use. Before purchasing equipment that requires backwashing, consult a local health department or cooperative extension office for information on any local restrictions.

Precoat Filters

Precoat filters require less space than media or multimedia filters that have the same filtering capacity. A precoat filter consists of a filter tank, a powdered filter aid, and a porous membrane called the septum that supports the filter aid. The pores in the septum are small enough to allow water through but not filter aid particles.

As untreated water enters the tank, it mixes with the filter aid and forms a cake that coats the septum. Suspended solids become trapped in the filter cake. Treated water passes through the filter cake and out of the device.

When the flow rate decreases to the point where insufficient treated water is produced, the filter aid is washed away with the trapped suspended solids and discarded or used as a soil amendment.

Uses

Precoat filters are point-of-entry (POE) devices that remove particles that cause turbidity; are prefilters that protect other treatment devices from suspended solids contamination; and are one step in removing iron, manganese, and hydrogen sulfide. Dissolved iron, manganese, or hydrogen sulfide must be oxidized into solid particles via chlorination or ozonation before they can be removed by a precoat filter. These chemical treatment methods are further described in chapter 3.

Properly designed precoat filters are recommended for removing protozoa, such as *Giardia lamblia* and *Cryptosporidium parvum,* and some forms of asbestos. The filter aid particles must be small enough to trap the protozoa or asbestos fibers. Protozoa resist chlorination and are more likely to be found in surface water than groundwater. Other methods for removing protozoa include cartridge filtration (see page 10), boiling (see page 32), and distillation (see page 33).

The filter aid is sometimes mixed with activated carbon to improve the treatment capabilities of the filtration unit. Activated carbon is capable of removing tastes, odors, and some organic chemicals. See the section on activated carbon beginning on page 26 for more information on its water treatment uses.

Principles

The precoat filter tank encloses the septum, which can be fabric, bronze, stainless steel, or a wire-wrapped cylinder. The septum is supported by a rigid structure called a filter element.

Initially, water enters the filter tank and mixes with filter aid, forming a $\frac{1}{16}$- to $\frac{1}{8}$-inch-thick filter cake on the septum. The septum pore size must be small enough to retain the filter aid so the filter cake can form. Figure 2.9 illustrates filter cake formation.

In a process called body feeding, additional filter aid is added to the incoming water to extend the filter run. Body feed doses can be increased for high concentrations of suspended solids.

As water continues to pass through the filter, the filter aid traps suspended solids, thus preventing the septum from clogging. The size of suspended solids trapped depends on the filter aid. If the filter aid is an activated carbon–based material, some tastes and odors may also be removed.

Filter aid comes in different grades or particle sizes that range from fine to coarse. Fine-grade filter aid removes smaller particles but produces a shorter filter run. Common filter aids are diatomaceous earth—a powder made up of the skeletal remains of sea organisms called diatoms—and perlite.

Capacity

The service flow rate of a precoat filter is determined by the surface area of the septum and ranges from 2 to 7 gallons per minute per square foot of septum area. The service flow rate decreases as the particle size decreases and as the suspended solids content increases.

Maintenance

When the filter cake becomes clogged and the filter no longer provides adequate treated water, remove the filter element. Wash the filter aid and accumulated solids from the filter element, then reposition the element in the filter tank. Add fresh filter aid to the inflow water to recoat the septum. The average replacement interval for filter aid is two months but will vary based on water quality, flow rate, and filter design.

Cleaning the filter element thoroughly is important. Any remaining suspended solids may clog the septum, and the filter may not provide its previous flow rate. When disposing of filter aid, consider the type of contaminant collected in the filter aid and its potential impact on the environment.

Special Considerations

Precoat filters are most effective in waters with low turbidity and low bacteria counts. They are not recommended for removing bacteria or viruses; disinfection is recommended instead. For more information on disinfection, see the sections on boiling (page 32), distillation (page 33), ultraviolet disinfection (page 34), chlorination (page 47), and iodination (page 56).

Asbestos fibers have been linked to increases in certain cancers. *Giardia lamblia* and *Cryptosporidium parvum* cause giardiasis and cryptosporidiosis—diseases that result in diarrhea, fatigue, and cramps. When using a precoat filter to remove these hazardous contaminants, proper operation and maintenance is crucial to ensure that they do not bypass the filter medium.

Reverse Osmosis

Reverse osmosis (RO) devices reduce the total dissolved solids (TDS) concentration in water. The simplest RO systems consist of a housing for the RO membrane and a storage container for treated water. Generally, RO systems also include a cartridge sediment prefilter to remove suspended solids and an activated carbon postfilter to remove undesirable tastes or odors and some organic chemicals. Some systems require an activated carbon prefilter to remove chlorine that could damage certain membranes. Figure 2.10 illustrates a typical RO treatment system.

Home RO units are often cylindrical and measure approximately 5 inches in diameter and 25 inches long, excluding the treated water storage tank and any

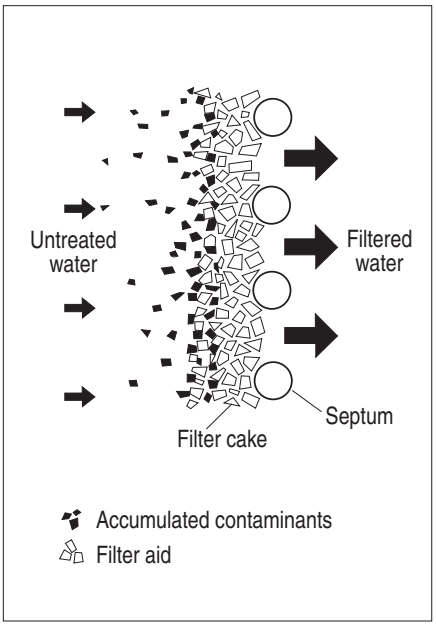

Figure 2.9
Precoat filter cake formation.

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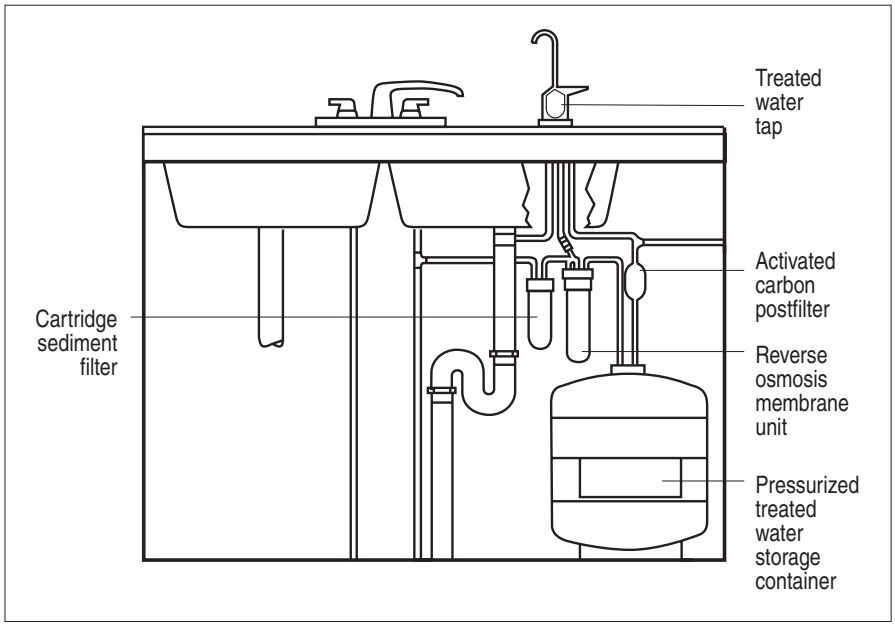

Figure 2.10
Reverse osmosis treatment system.

Source: Linda Wagenet and Ann Lemley. "Reverse Osmosis Treatment of Drinking Water," *Water Treatment Notes,* Fact Sheet 4, Cornell Cooperative Extension (1988).

pretreatment or posttreatment devices. Untreated water is diverted to the RO unit from the cold water line near the point of use—often beneath the kitchen sink. A separate water tap delivers treated water for drinking and cooking. A TDS meter is usually attached to the treated water tap to monitor the device's performance.

Uses

RO units are point-of-use (POU) devices and are recommended to reduce the concentration of most inorganic components of TDS—including aluminum, arsenic, barium, bicarbonate, boron, cadmium, calcium, chloride, chromium, copper, fluoride, lead, magnesium, manganese, mercury, nitrate, orthophosphate, potassium, selenium, silica, silver, sodium, sulfate, and zinc. Certain forms of each of these contaminants may be more easily removed from water than other forms. Be aware of the exact nature of the contaminant in question before assuming sufficient removal by an RO device. Although RO devices reduce the amount of a particular contaminant, they may not reduce the concentration to a nonhazardous level.

RO systems also effectively remove some organic chemicals but are usually not recommended for these contaminants. If using an RO device to remove an organic chemical, test the device for the specific chemical in question. The ability of an RO device to remove a specific organic contaminant depends on the membrane as well as other system factors, such as pretreatment and posttreatment devices. Activated carbon (see page 26), distillation (see page 33), or aeration (see page 57) may be preferable to an RO system for removing organic chemicals.

RO systems are not recommended for microbiologically unsafe water. Although the RO membrane is capable of removing virtually all microorganisms, it can develop pinholes or tears that allow bacteria or other microorganisms to pass into the treated water. A single exposure to a microorganism can cause adverse health effects. Small doses of toxic chemicals, however, can be tolerated by the human body for short periods of time.

Principles

During reverse osmosis, water molecules are forced through a semipermeable, cellophane-like membrane. As is illustrated in figure 2.11, the membrane allows water to pass through it, but dissolved solids movement through the membrane is limited. The concentration of dissolved solids in the untreated water increases as water passes through to waste.

Two streams of water emerge from the RO device. Ten to 20 percent of the water passes through the membrane and exits the device as treated water. The other 80 to 90 percent contains any material that did not permeate the membrane; this wastewater is diverted to the drain. Percentages vary with the pressure, quality, and temperature of the water; the characteristics of the semipermeable membrane; and the concentration and chemical formulation of the contaminants present in the untreated water.

Some RO systems have a shut-off valve to stop water flow when the storage tank is full. Others continue to divert water, sending all of the incoming wa-

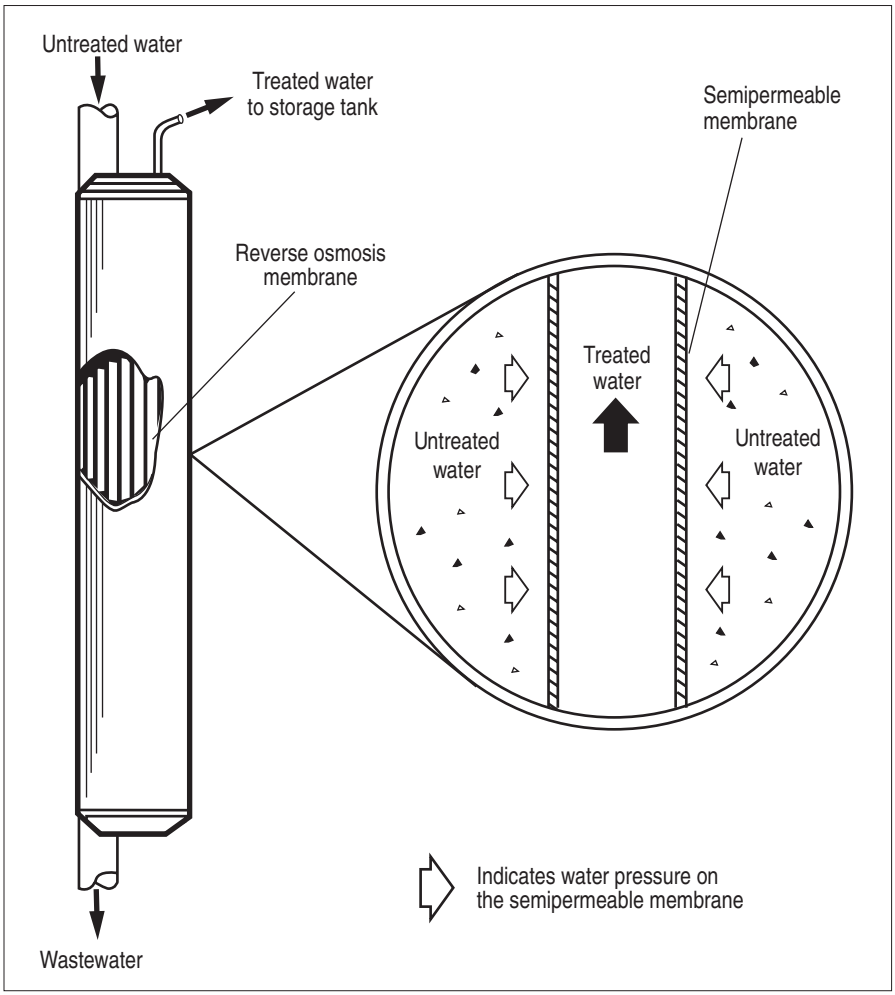

Figure 2.11
Reverse osmosis device.

ter to the drain when the storage tank is full. If a unit does have a shut-off valve, less water is wasted but the membrane life may be adversely affected. To conserve water, certain states are considering legislation to require a shut-off valve on all RO systems.

Water pressure is one of the key elements in an RO system—a higher water pressure results in more effective contaminant removal and a larger quantity of treated water. POU systems usually use household water pressure (30 to 60 pounds per square inch) as the driving force. The home water pressure required by a particular RO system depends on factors such as the TDS concentration in the untreated water and the pressure on the treated water side of the membrane.

In reverse osmosis, a constant pressure termed osmotic pressure exists on the treated water side of the membrane. This pressure must be overcome by the incoming water pressure for reverse osmosis to work. Figure 2.12 helps illustrate why. Side B contains the untreated water and side A contains treated water. If pressure is not applied to either side, osmosis naturally occurs and water moves from A to B—that is, from low TDS to high TDS, as is illustrated in the upper portion of the figure. In reverse osmosis, however, a pressure must be exerted on side B to overpower the natural movement toward side B and force pure water across the membrane to side A.

The pressure needed to prevent water movement from A to B must equal the osmotic pressure. For each 100 milligrams per liter TDS in the untreated water, approximately 1 pound per square inch of osmotic pressure must be overcome. Therefore, if the TDS concentration is 1,000 milligrams per liter, about 10 pounds per square inch pressure must be applied to side B.

If the RO system includes a pressurized storage vessel for treated water, the pressure in the vessel increases as it fills. This back pressure must also be overcome to push water from B to A. Therefore, the net available pressure is calculated by subtracting the osmotic pressure and the back pressure from the household water pressure.

For example, assume that the household water pressure is 60 pounds per square inch, the osmotic pressure is 10 pounds per square inch, and the storage tank back press-ure varies from 5 to 40 pounds per square inch. The presure available to push water across the membrane will vary from 45 pounds per square inch (60 minus 10 minus 5) to 10 pounds per square inch (60 minus 10 minus 40). The increasing pressure in the storage tank leads to a decrease in available pressure, and, as a result, a decrease in the percentage of treated water recovered and in the

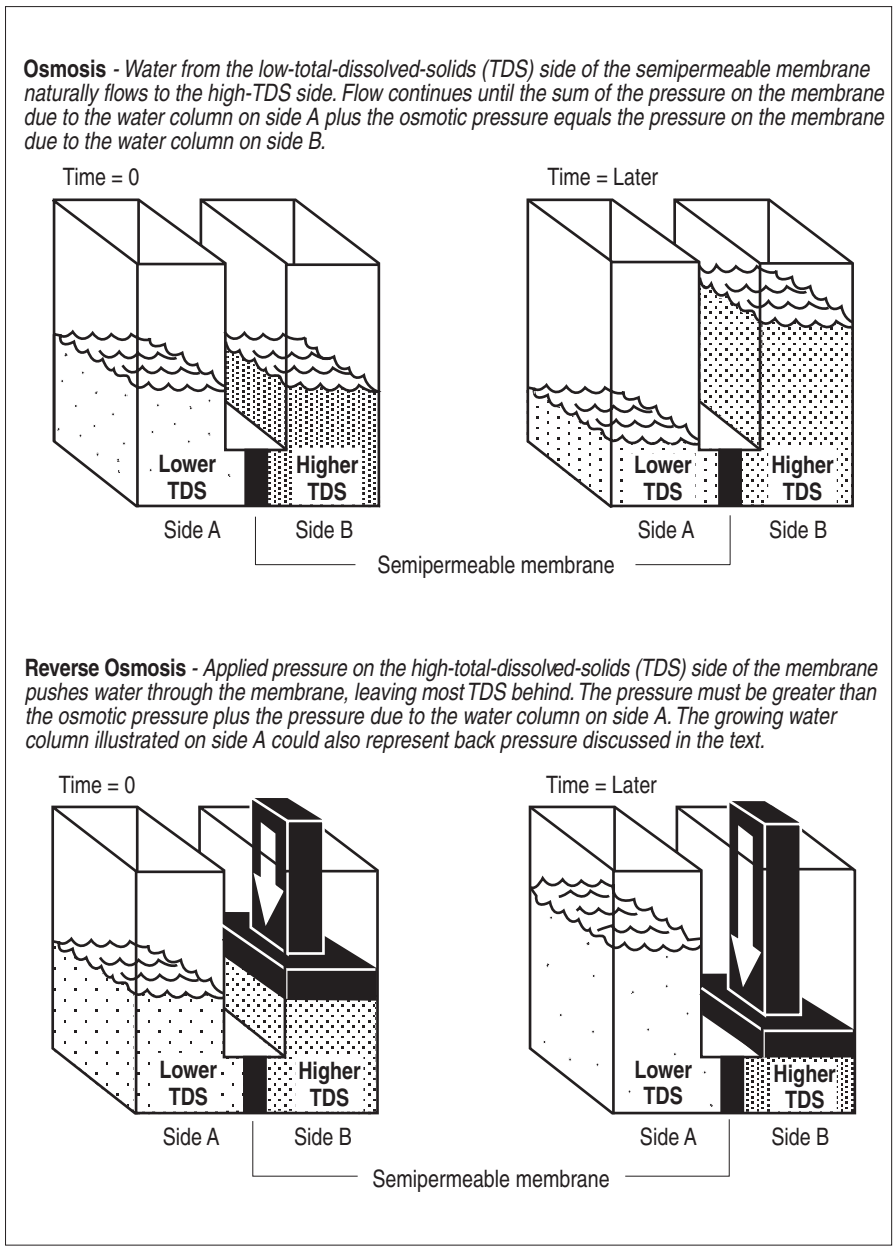

Figure 2.12
Principles of osmosis and reverse osmosis.
Adapted with permission from *Water Technology* magazine.

amount of contaminant that passes through the membrane.

Water temperature also has a significant impact on RO performance—the higher the temperature, the better the performance. Many RO devices are tested at an incoming water temperature of 77 degrees Fahrenheit. Groundwater temperature is about 55 degrees Fahrenheit. The amount of treated water from an RO unit decreases by 30 to 40 percent if the water temperature is 55 degrees Fahrenheit instead of 77 degrees Fahrenheit.

An RO device seldom stands alone—it is part of a system of devices. Refer to figure 2.10 for an illustration of a typical RO treatment system. Pretreatment and posttreatment devices are usually necessary depending on the quality of the untreated water. High concentrations of iron, manganese, and hydrogen sulfide; excessive hardness; and high turbidity can damage the membrane and clog the RO device. To protect the membrane and prevent clogging, correct such conditions with a cartridge sediment prefilter—usually one with a 5-micron rating. For more information on cartridge sediment filtration, see page 10. Add a water softener if the hardness is greater than 10 grains per gallon (180 milligrams per liter). Water softeners are discussed beginning on page 41 of chapter 3.

Activated carbon pretreatment is needed only if the water is chlorinated and chlorine-sensitive RO membranes are used. Activated carbon can also be a posttreatment device for remov-ing some organic chemicals and dissolved gases not removed by the RO device. For a more detailed discussion of activated carbon and its capabilities, see the section beginning on page 26.

Types

Various membranes and membrane structures exist for RO devices. Membranes are approximately 2 inches in diameter by 12 inches long and are inserted into a plastic housing similar to those used in other treatment devices. The most common materials used are cellulose acetate (CA), cellulose triacetate (CTA), polyamide, and a thin-film composite (TFC) composed of a modified polyamide. Table 2.3 compares some of the different membranes.

Generally, polyamide and TFC membranes operate over a wider pH range and are more resistant to biological attack than are CA or CTA membranes. Polyamide and TFC membranes are also easier to clean and have a somewhat better rejection rate for ionic contaminants. They cannot resist chlorine, however, and CA or CTA membranes are recommended for use on chlorinated water if no activated carbon prefilter is included to remove chlorine.

Certain RO membranes are designed specifically to overcome low household water pressure. Some studies have shown TFC membranes to have a greater contaminant removal capacity at very low water pressures than CA membranes.

The two types of RO membrane structures are spiral-wound and hollow-fiber. In each case, the structure is designed to increase the surface area that comes into contact with untreated water. The larger the surface area, the greater the flow rate.

Spiral-wound membranes are more common than hollow-fiber membranes in home systems. Spiral-wound membranes are designed to treat water with high levels of dissolved solids. They consist of two layers of semipermeable membrane that are separated by a woven fabric such as nylon, Dacron, or polyester. This membrane "sandwich" is then spiraled around a tube.

Hollow-fiber membranes are manufactured by spinning the material into thin fibers that are bundled together in a "U" shape or straight line. These fibers are wrapped around a supporting structure. Hollow-fiber membranes are easily clogged by hard water, but they require less space and are somewhat easier to maintain than spiral-wound membranes.

Capacity

RO units have a limited flow rate capacity and therefore usually treat only drinking and cooking water. Units that operate at household water pressure (about 30 to 60 pounds per square inch) yield about 3 to 5 gallons per day.

When evaluating an RO system, determine if the gallons-per-day claims are for the whole system—including prefilters, postfilters, and the storage tank—or just for the RO device. If the production claims are only for the RO device, to determine the pressure available for the RO device, subtract the reduction in water pressure that occurs in pretreatment devices from the water pressure entering the system.

A booster pump can be added to raise water pressure to over 100 pounds per square inch, resulting in an increased yield of 10 to 15 gallons per day. When selecting a booster pump, consider the flow capacity, inlet pressure requirements, outlet pressure, noise, energy efficiency, and cost.

The percent recovery of treated water for a particular RO system is determined by dividing the amount of treated water by the amount of untreated water and multiplying by 100.

$$\text{percent recovery} = \frac{\text{gallons treated water}}{\text{gallons untreated water}} \times 100$$

For example, assume that an RO unit produces 5 gallons of treated water for every 50 gallons of untreated water. The percent recovery would be:

$$\text{percent recovery} = \frac{5 \text{ gallons}}{50 \text{ gallons}} \times 100 = 10 \text{ percent}$$

Variability in recovery percentages is usually due to design characteristics of the RO unit, water temperature, water pressure, the ability of the RO unit to handle differing levels of TDS, and other factors.

The percent rejection for a specific contaminant or for TDS is easily calculated. First, measure the contaminant concentration in the untreated water and the concentration in the treated water. The percent rejection is then calculated with the following formula:

$$\text{percent rejection} = \frac{\text{untreated conc.} - \text{treated conc.}}{\text{untreated conc.}} \times 100$$

For example, consider untreated water with a lead concentration of 0.128 milligram per liter. If RO treatment reduces the lead concentration to 0.008 milligram per liter, then the percent rejection of lead would be:

$$\text{percent rejection} = \frac{0.128 - 0.008}{0.128} \times 100 = 94 \text{ percent}$$

When checking a manufacturer's claims for percent rejection rates, be sure to note the pressure under which the advertised rejection rates were achieved. Devices for in-home use are usually tested at 50 pounds per square inch of pressure, and most household water pressure is somewhere between 30 and 60 pounds per square inch.

Maintenance

RO membranes have a lifetime of three to five years. Eventually the RO membrane tears, allowing dissolved solids to pass through. The membrane must then be replaced.

Since it is impractical to visually inspect the membrane for tears, test treated water at installation and regularly after installation to monitor RO performance. Test water more frequently if removing hazardous contaminants.

Monitoring methods for RO systems are based on service time, gallons of water treated, or TDS concentration. A TDS monitoring device attached to the delivery faucet is best because it

Table 2.3
Comparison of reverse osmosis membranes

Membrane	Flux [a] (gallons/ square foot/day)	Percent rejection of mixed ions [a, b]	pH tolerance	Resistance to biological degradation	Temperature range (˚F)	Factors promoting performance degradation
Cellulose acetate (CA)	1	88 to 92	5.5 to 8	Poor resistance; requires chlorination for disinfection	40 to 85	High pH High temperature
Blend [c]	1	92 to 94	5.5 to 8.5	Somewhat resistant	40 to 85	High pH High temperature
Cellulose triacetate (CTA)	1	94 to 96	5.5 to 9	Good resistance	40 to 95	High pH High temperature
Thin-film composite (TFC)	2	96 to 98	4 to 11	Total resistance	40 to 120	Chlorine and other oxidants

Source: Adapted by permission from *Water Conditioning and Purification* magazine, December 1983.

[a] Values are for feed water under 65 pounds per square inch pressure and having a 70-degree-Fahrenheit temperature and a 500 milligrams per liter mixed-ion total dissolved solids (TDS) concentration.

[b] Reverse osmosis does not completely remove a contaminant; some will pass through the membrane. How much contaminant passes through depends on the concentration and chemical formulation of the contaminants present in the untreated water as well as water quality parameters and system characteristics.

[c] These membranes are made of a blend of cellulose acetate (CA) and cellulose triacetate (CTA).

monitors actual water quality and may detect an early tear in the membrane or untreated water bypassing the membrane. A sudden change in TDS indicates that either the RO device or a prefilter is malfunctioning. A sudden decrease in treated water flow may indicate either a clogged RO membrane, in which case the membrane must be replaced, or a clogged prefiltration or postfiltration device.

When a hazardous contaminant such as nitrate or lead is present, monitor specifically for the contaminant rather than TDS. Nitrate is especially hazardous to infants, as infants who ingest water containing a high nitrate concentration are at risk of developing methemoglobinemia, or blue baby syndrome. Long-term consumption of water with a high lead concentration can result in chronic health effects such as cancer and brain damage. For more information on water testing, see *Private Drinking Water Supplies: Quality, Testing, and Options for Problem Waters,* NRAES–47.

Although the storage container in the RO system should be presterilized, certain bacteria may still colonize the tank. Periodic cleaning may be necessary. Some systems may have a disinfection system installed after the storage tank.

Since the RO system may include a cartridge sediment prefilter for removing suspended solids; an activated carbon prefilter for removing chlorine; and an activated carbon postfilter for removing unpleasant tastes, odors, and certain organic chemicals, maintenance is not limited to changing the RO membrane and monitoring treated water quality. Before purchasing an RO system, consider the cost to maintain the entire system and compare it to other options for a safe water supply.

Special Considerations

Before purchasing an RO system, investigate other treatment options. Most inorganic contaminants can also be removed by distillation, which is discussed beginning on page 33. Other alternatives, such as buying bottled water, could be more cost-effective.

Drawbacks to RO systems are that they waste water, may be expensive, generally produce water solely for drinking and cooking, and require pretreatment and posttreatment. Any pretreatment and posttreatment devices require additional maintenance.

If using an RO unit equipped with a shut-off valve, the danger exists of contaminating other water lines in the household. When the valve is activated, pressure in the RO system goes to zero. Since the RO wastewater line is often directly connected to a drain line in the residential plumbing system, sewage could conceivably flow up into the potable water supply when pressure on the RO system abates. Residential plumbers can offer a variety of ways to avoid such backflow.

Some systems are advertised as being able to remove certain organic chemicals. Such claims are usually due to activated carbon pretreatment or posttreatment devices, not the RO device. As with all water treatment devices, be careful not to buy a more elaborate treatment system than is needed.

Adsorption

Adsorption is the process by which one substance adheres to the surface of another substance termed the adsorbent. In adsorption systems, the adsorbent accumulates and retains contaminants as water passes through the system. While filters block contaminants, adsorption devices rely on an attraction between the adsorbent and the contaminants that holds the contaminants to the adsorbent surface. Figure 2.13 illustrates this concept.

Confusion often exists about the process of *adsorption* versus the process of *absorption*. A sponge illustrates the difference. Water is absorbed into and becomes part of a sponge while soil is adsorbed onto the surface of a sponge.

The ability of an adsorption device to remove a contaminant depends on

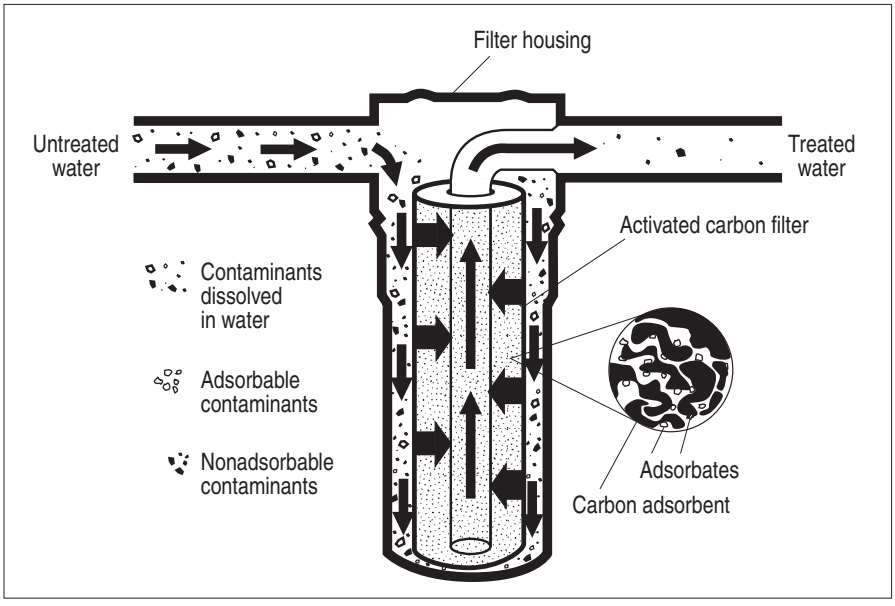

Figure 2.13
The adsorption process.

several factors, including the type and amount of adsorbent, the design of the device, the contact time between the adsorbent and the water, contaminant characteristics, and general water quality.

The media used in devices in this section are activated carbon and activated alumina. Considering the medium as a column, if the water flow rate is appropriately slow, the contaminant adsorbs instantaneously onto the medium at the top of the column. This creates a zone of adsorption that migrates down the column as adsorption sites fill and upper parts of the column become saturated with contaminant. In this manner, untreated water encounters progressively cleaner adsorbent as it travels down the column. The zone of adsorption is illustrated in figure 2.14.

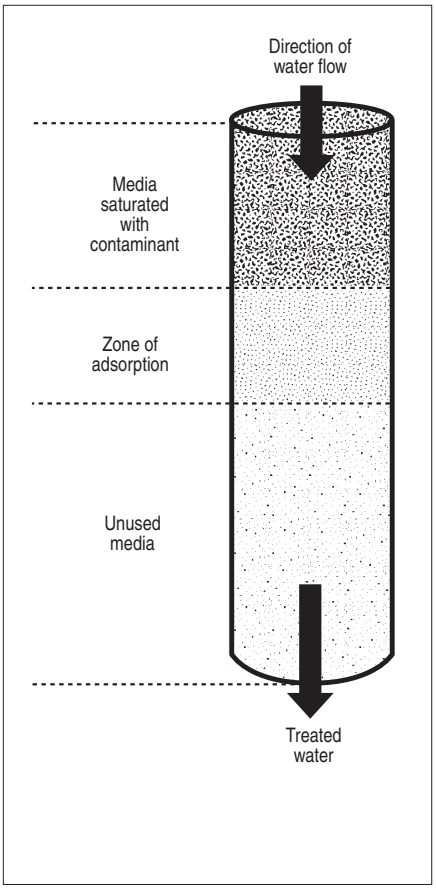

Figure 2.14
The zone of adsorption.

As the zone of adsorption approaches the end of the column, less contaminant is removed from the water since fewer sites are available for adsorption. The contaminant may eventually breakthrough, or exceed an acceptable concentration, as is illustrated in figure 2.15. If water continues to pass through the device, the entire adsorption medium becomes saturated with contaminant, and the contaminant concentration in the treated water will equal that of the untreated water.

If the untreated water has more than one chemical that can be adsorbed, the effectiveness of the device in removing a particular contaminant depends on the strengths of attraction between the contaminants and the adsorbent. For example, consider untreated water that contains two different chemicals—one that is strongly adsorbed (contaminant A) and one that is weakly adsorbed (contaminant B). As water passes through the device, a zone of adsorption for con-

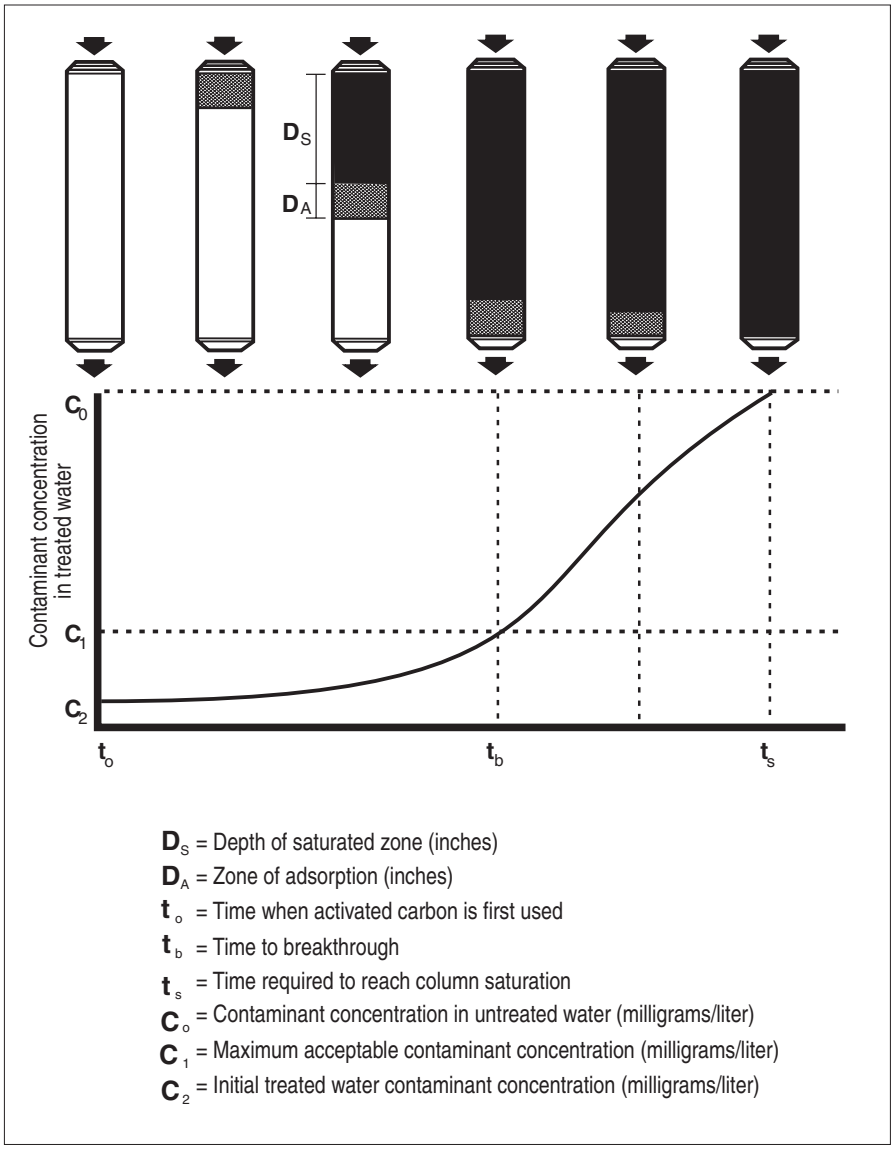

Figure 2.15
Contaminant breakthrough.
Adapted with permission from *Water Technology* magazine.

taminant A develops in the upper part of the column. In time, the zone moves down the column, leaving the medium behind it saturated with contaminant A.

Since contaminant A is preferentially adsorbed by the medium, the adsorption zone for contaminant B exists below that of contaminant A. As the adsorption zone for contaminant A migrates down into the area saturated with contaminant B, contaminant B can be displaced by the more strongly attracted contaminant A. The displaced contaminant B is then added to the passing water. Thisprocess is called dumping, or unloading, and may result in treated water with a higher concentration of contaminant B than that in the untreated water. Before purchasing an adsorption device, test water to determine whether other contaminants are present that may affect the adsorption process.

Contaminant breakthrough and dumping are concerns for both activated carbon and activated alumina devices—especially when they are used to remove tasteless, odorless chemicals. In such cases, the capacity of the device should be determined by regularly testing the treated water until breakthrough occurs.

Activated Carbon Filters

Although these devices are commonly known as carbon filters, they actually adsorb contaminants to an activated carbon medium instead of physically blocking them, as cartridge or media filters do. The effectiveness of these devices depends on the type and amount of activated carbon used, the device design, the contact time between the adsorbent and the water, contaminant characteristics, and general water quality. Activated carbon filters are recommended for use only on microbiologically safe water.

Uses

Carbon filters can be either point-of-entry (POE) or point-of-use (POU) devices. They reduce unpleasant tastes and odors as well as levels of chlorine, iodine, radon gas, and a wide variety of organic chemicals—including petroleum products, pesticides, and trihalomethanes (THMs). Table 2.4 provides information on the use of activated carbon for various contaminants.

While activated carbon is the most effective treatment for many organic chemicals, it is not appropriate for all of them. Table 2.5 compares adsorption levels for various organic chemicals. An explanation of the chemical classes in the table is beyond the scope of this publication, but the table is helpful in assessing which organic chemicals can be effectively removed with activated carbon. See appendix A for more information about using activated carbon to remove a specific organic chemical.

Principles

Activated carbon is a specially treated carbon source derived from petroleum coke, bituminous coal, lignite, or wood products. The carbon source is crushed and heated to between 500 and 1,800 degrees Fahrenheit. The heating action produces a network of large and small pores called macropores and micropores, respectively. When water passes through activated carbon, certain contaminants adsorb to the pore structure.

Table 2.4
Guidelines for the use of activated carbon

Contaminant	Comments or cautions
Bacteria, viruses, cysts	Microorganisms should be eliminated before activated carbon treatment.
Chlorine	Leaves no residual chlorine for disinfection.
Organic chemicals [a]	Use petroleum, lignite, or coal-based activated carbon. Do not use pour-through or faucet-mount devices.
Petroleum/gasoline byproducts [a]	Use petroleum, lignite, or coal-based activated carbon. Do not use pour-through or faucet-mount devices.
Volatile organic chemicals (VOCs) [a]	Use point-of-entry devices. Investigate aeration as an alternative (see page 57).
Radon	Use point-of-entry devices. Radon is held in activated carbon until it decays. Do not backwash. Investigate aeration as an alternative (see page 57).
Lead	Only use devices specially designed for removing lead. Water quality can affect the lead removal capabilities of activated carbon.

Source: Revised from Linda Wagenet and Ann Lemley, "Activated Carbon Treatment of Drinking Water," *Water Treatment Notes,* Fact Sheet 3, Cornell Cooperative Extension (1987).

Note: The types of carbon and activated carbon devices mentioned in this table are explained more fully later in this section.

[a] Activated carbon is not effective for all contaminants in this category. Other treatment methods may be more effective. See appendix A for more information.

Table 2.5
Readily and poorly adsorbed organics

Readily adsorbed organics

- Aromatic solvents (benzene, toluene, nitrobenzenes)
- Chlorinated aromatics (PCBs, chlorobenzenes, chloronaphthalene)
- Phenol and chlorophenols
- Polynuclear aromatics (acenapthene, benzopyrenes)
- Pesticides and herbicides (DDT, aldrin, chlordane, heptachlor)
- Chlorinated nonaromatics (carbon tetrachloride, chloroalkyl ethers)
- High molecular weight hydrocarbons (dyes, gasoline, amines, humics)

Poorly adsorbed organics

- Alcohols
- Low molecular weight ketones, acids, and aldehydes
- Sugars and starches
- Very high molecular weight or colloidal organics
- Low molecular weight aliphatics

Source: U.S. Environmental Protection Agency, Technologies for Upgrading Existing or Designing New Drinking Water Treatment Facilities, Document EPA/625/4-89/023.

Note: Standards and health advisories issued by the U.S. Environmental Protection Agency may have further information concerning the use of activated carbon for a specific contaminant. See appendix A, tables A.1 and A.2, beginning on page 64.

Micropores within activated carbon range in size from 0.001 to 10 microns in diameter. Micropores result in a surface area within activated carbon of 275,000 to 366,000 square feet per ounce. Macropores in the carbon guide untreated water throughout the activated carbon to the micropores, where most of the adsorption takes place.

Several forms of activated carbon can be used in activated carbon filters. Granular activated carbon, the most common type used in home water treatment units, varies by particle size, particle density, pore size, and surface area. It is most effective in removing chemicals with low solubility—that is, those that do not dissolve easily. Granular activated carbon is not recommended for use as a mechanical filter.

Powdered activated carbon removes tastes and odors. It can be included in multimedia filters (see page 16) and precoat filters (see page 18) to add taste and odor removal capabilities. Powdered carbon that is pressed into a block is less apt to channel—that is, create preferential flow patterns. The reduced pore spaces are easily clogged, however, and may result in significant water pressure loss.

Block carbon is effective in removing certain organic chemicals. A few manufacturers have claimed that some configurations successfully remove lead. However, using block carbon to remove inorganic chemicals such as lead and mercury is controversial, since the pH and chemical composition of the water as well as the physical form of the chemical can greatly affect removal capabilities. Be especially careful when considering activated carbon to remove an inorganic chemical whose concentration exceeds the maximum contaminant level (MCL) set by the U.S. Environmental Protection Agency (EPA). Refer to table 1.3 on page 8 or tables A.1 and A.2 in appendix A for other treatment methods recommended for specific inorganic contaminants.

Because adsorption is an equilibrium process, sudden changes in the contaminant concentration may cause the activated carbon to release previously adsorbed contaminant into the water. Therefore, water with a variable contaminant concentration may result in inconsistent treated water quality. Causes of variable contaminant concentrations are discussed in chapter 1 on page 6.

Other contaminants in the water besides the targeted contaminants may affect the efficiency of activated carbon. This phenomenon, known as dumping or unloading, is discussed in the introduction to the adsorption section, which begins on page 24. If a contaminant is known to cause adverse health effects, it is important that the untreated water be tested for other contaminants that may interfere with activated carbon treatment.

To prevent clogging, turbidity should be removed with a 5-micron cartridge sediment filter prior to activated carbon treatment. Sediment filter discussion begins on page 10. Pretreatment to remove iron and manganese may also be required. See table 3.5 on page 47 for a summarization of methods used to remove iron and manganese.

Types

The five types of activated carbon units are pour-through, faucet-mount, in-line, line-bypass, and POE. The particular activated carbon device appropriate for a given situation is determined by the type and concentration of the contaminant and the unit's de-

sign—particularly how much carbon it contains. The types of activated carbon devices are illustrated in figure 2.16. The same plastic housing used for some activated carbon filters may also be used to enclose cartridge sediment filters or reverse osmosis (RO) membranes. Be sure to examine filter information completely before purchasing a device.

Pour-through and faucet-mount units should be used only for nonhazardous taste and odor problems and when small amounts of water are to be treated. Pour-through devices are similar to a drip coffee maker. Faucet-mount units attach to a faucet, usually the kitchen faucet. Both are inexpensive but do not contain enough activated carbon or provide sufficient contact time between the carbon and water for reliable contaminant removal. Installation is simple, and maintenance is required when the tastes or odors return or when the device becomes clogged. The filter material is usually replaced, not backwashed. Significant bacterial growth can occur on the carbon in these units, so they should be thoroughly flushed if unused for more than a few days.

In-line devices are usually installed in the cold water line beneath the kitchen sink. Diverting water from the unit for uses other than drinking or cooking is not an option. If hot and cold water come from a single tap, the hot untreated water may mix with the cold treated water in the faucet. This problem does not occur with line-bypass units.

Line-bypass units are attached to the cold water line and have a separate faucet for delivering treated water. The separate faucet system slows the flow rate, which increases contact time and adsorption effectiveness.

Neither in-line nor line-bypass units are recommended for removing radon or volatile organic chemicals (VOCs). Inhaling these chemicals is more hazardous than ingesting them, and since exposure may occur when the chemicals vaporize from showers, dishwashers, or washing machines, POE devices that are vented outside the home are recommended.

POE devices are installed where water enters the house, so they treat all water used in the home. There is no bypass option for in-home uses, although water can be diverted for outdoor use prior to treatment. These devices are recommended for treating radon, VOCs, and other contaminants necessitating that treated water be provided throughout the house. Systems used for removing VOCs should be vented to the outside atmosphere.

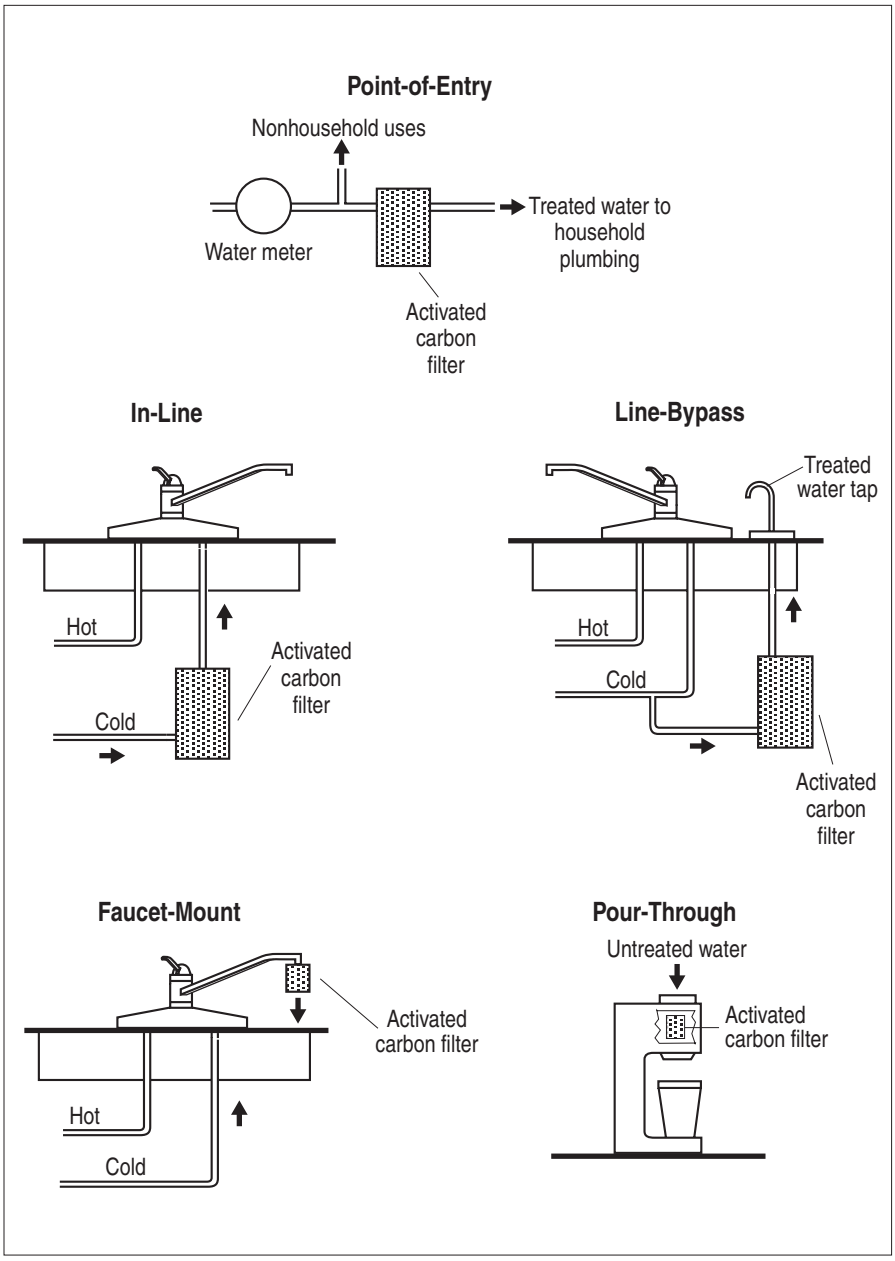

Figure 2.16
Types of activated carbon units.

Source: Adapted from Linda Wagenet and Ann Lemley, "Activated Carbon Treatment of Drinking Water," *Water Treatment Notes,* Fact Sheet 3, Cornell Cooperative Extension, December 1987.

Capacity

The flow rate and contaminant removal capacity are the two factors that determine the total capacity of an activated carbon device. The flow rate depends on the surface area and micropore network of the activated carbon and the available pressure. As the surface area increases, so does the flow rate as long as other factors remain equal. POE units provide a larger surface area in contact with untreated water than single-tap devices and therefore have a greater flow rate capacity. The size of the micropore network determines the likelihood of clogging—the smaller the micropores, the higher the chance of clogging. If the filter becomes clogged, the flow rate decreases. Available pressure directly affects flow rate—the higher the pressure, the higher the flow rate.

At a water pressure of 30 pounds per square inch, POE units should produce a flow rate between 4 and 10 gallons per minute, and the pressure loss for these systems should not exceed 3 to 5 pounds per square inch. Line-bypass units produce 1 gallon per minute at normal household pressure, with a pressure loss of about 1 pound per square inch.

The contaminant removal capacity is determined by the contact time, which is determined by the flow path, the device design, the flow rate, and the network of micropores. The contact time of a typical POU unit is less than three minutes, whereas POE systems have contact times extending to thirty minutes.

Figure 2.17 illustrates two water flow paths that may occur in activated carbon devices: longitudinal and radial. In a longitudinal design, the water flows from the bottom to the top of the device or vice versa. In a radial flow design, the water flows from the outside to the center. For equal volumes of carbon, the longitudinal flow design has a greater contact time and is therefore better for removing health-related contaminants. A radial flow path, however, provides more surface area for flow and has a higher flow rate. Radial designs are adequate for taste and odor removal. The filter media in radial designs may be wrapped with wound string or plastic or wire mesh to remove sediment particles.

For POE devices, in general, taller, thinner filter tanks provide a longer contact time than shorter, rounder tanks with the same amount and type of activated carbon. For example, a tank that is 54 inches long with a 10-inch diameter would provide a longer contact time than a tank that is 36 inches long with a 12-inch diameter. This is because, in the 10-inch-diameter tank, the water must travel a longer path through the filter. The 12-inch-diameter tank would have a higher flow rate than the 10-inch-diameter tank, but the 10-inch tank would have a greater contaminant removal efficiency.

The primary determinant of contaminant removal capacity among the various activated carbon filters is the amount of carbon in the device. The more carbon a filter contains, the larger its capacity for adsorption. Table 2.6 describes the approximate volume and mass of activated carbon in pour-through, line-bypass, in-line, and POE activated carbon devices.

The type of activated carbon a device contains also affects the quantity and type of contaminants it can remove.

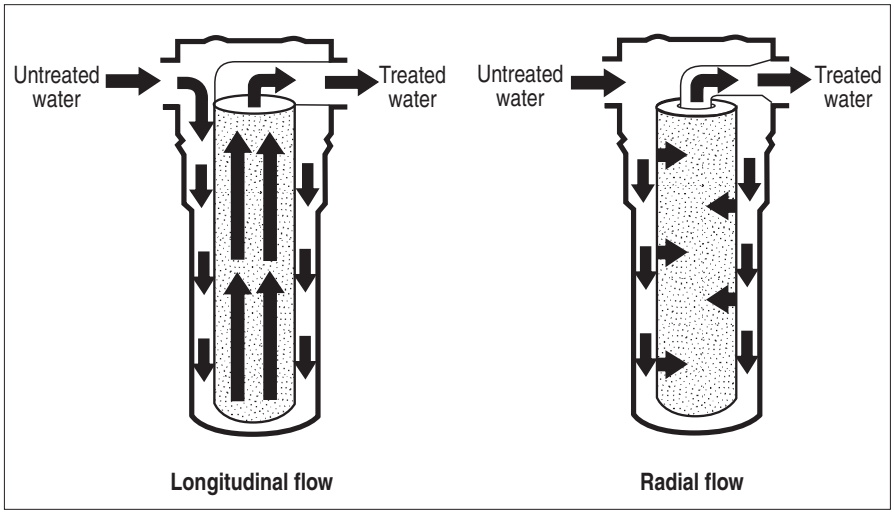

Figure 2.17
Water flow paths in activated carbon units.

Table 2.6
Approximate amounts of activated carbon in treatment devices

Device type	Approximate volume of carbon (cubic feet)	Approximate mass of carbon (pounds)
Pour-through	0.002 to 0.018	—
Line-bypass or in-line	0.035 to 0.10	0.6 to 1.8
Point-of-entry	>1.0	22 to 44

Source: Data reprinted from Paul Schorr, *Point of Use Device: Granular Activated Carbon,* State of New Jersey Department of Environmental Resources, Division of Water Resources (September 1988).

Refer to page 27 for a complete discussion on the types of carbon available. Types vary according to the original carbon source, the method used for activation, the temperature at which the carbon is formed, and the size of the micropores.

When the contaminant to be removed has potential adverse health effects, two activated carbon devices can be connected in a series to increase contaminant removal efficiency. This is illustrated in figure 2.18. Should contaminant breakthrough occur in the first device, the second device would offer additional protection. To ensure that a fresh backup device is always available, when the first device fails, the second device is moved into its place. A fresh device is then installed in the second position.

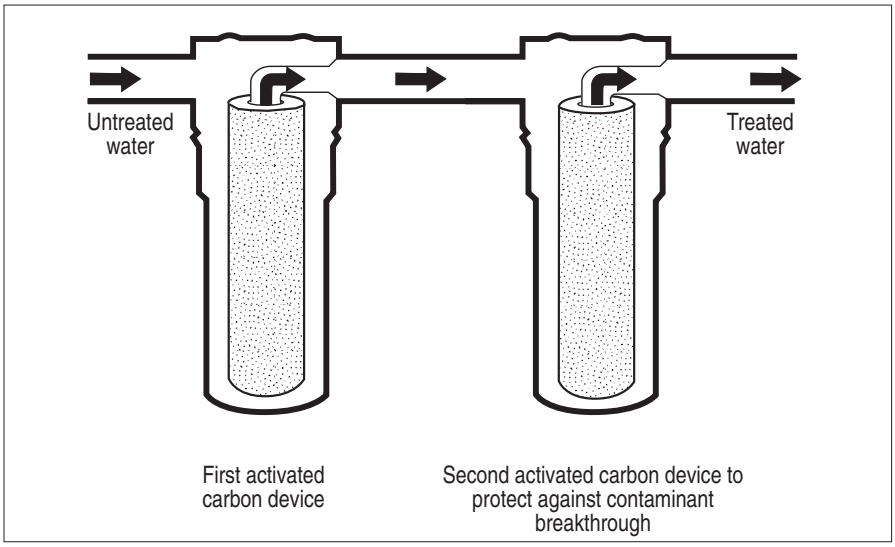

Figure 2.18
Using two activated carbon units to protect against breakthrough.

Maintenance

Maintaining activated carbon devices may involve replacing the activated carbon, backwashing, or both. Maintenance may also involve testing the water periodically. Manufacturers usually suggest guidelines for maintenance frequency based on gallons of water treated or time the device is in operation. Guidelines will vary with water quality and flow rate. Maintenance recommendations based on an avoidance of bacteria buildup should take precedence over other recommendations.

Immediately after installing a device, test treated water once per month until the unit's contaminant removal capacity is established. The capacity is reached when the concentration of the contaminant in the treated water exceeds the safe or acceptable level determined by EPA drinking water standards (see appendixes A and B). Once the capacity is known, establish a maintnance schedule based on gallons of water treated or time in operation. Be aware that the concentration of any contaminant in groundwater may change with time, so occasional testing is still necessary. For more information on contaminant fluctuations in groundwater, see page 6 in this publication, or see *Private Drinking Water Supplies: Quality, Testing, and Options for Problem Waters,* NRAES–47.

Backwashing activated carbon flushes any trapped particles and some adsorbed contaminants from the device. Backwashing is not recommended if the contaminant being removed has potential adverse health effects, as the wastewater may contain a high concentration of contaminants and may present a disposal problem. Backwashing can also disrupt the position of activated carbon particles in the bed and release adsorbed material into the treated water.

If backwashing is not an option, a carbon cartridge saturated with contaminant can be regenerated by burning off the contaminants and reactivating the carbon. Commercial water treatment firms offer such regeneration services.

A final alternative to backwashing is to discard the exhausted carbon cartridge as solid waste. When disposing of cartridges, consider the type of contaminant collected in the cartridge and its potential impact on the environment.

Special Considerations

Bacterial growth is a potential problem encountered with activated carbon units. Both the activated carbon and any adsorbed organic contaminants are a growth medium for bacteria. Chlorination may eliminate bacteria on the activated carbon but will also "use up" the carbon's contaminant removal capacity. If the activated carbon is being used to remove organic chemicals, chlorine may displace or degrade the organic chemicals; chemical degradation may result in unknown byproducts. Activated carbon treatment should be used only on microbiologically safe water.

If a filter has not been used for more than five days, to reduce the amount of bacteria in the treated water, run water through the device for thirty seconds or until 1 to 2 quarts have passed through it. Some manufacturers claim that infusing compounds such as silver into the carbon prevents bacterial growth on the carbon surface. Current research, however, does not support this claim.

Before purchasing activated carbon equipment for VOCs or radon, investigate aeration as a treatment option.

This treatment method is described beginning on page 57. Aeration may be preferred, as it has no medium that will accumulate high concentrations of hazardous materials. Activated carbon used for radon removal can become a low-level radiation source within the home.

Activated Alumina

Similar to activated carbon, activated alumina adsorbs contaminants instead of filtering them. The effectiveness of activated alumina depends on the contaminant, characteristics of the alumina, the device design, and water quality.

Uses

Activated alumina can be a point-of-entry (POE) or point-of-use (POU) device. It reduces the concentration of fluoride, arsenic, selenium, and chromium in water. For each of these contaminants, reverse osmosis (discussed on page 19) and distillation (discussed on page 33) are other options for removal.

For arsenic removal, anion exchange (discussed beginning on page 45) is an alternate treatment. The choice between activated alumina and anion exchange depends on the water quality and maintenance considerations. If the water has a high total dissolved solids (TDS) level or sulfate concentration, activated alumina would be more effective. However, a serious drawback to using activated alumina is that regenerating it requires the use of strong acid and base solutions that are undesirable for home storage and handling. Anion exchange resin, on the other hand, can be regenerated at home with less dangerous chemicals.

Principles

Activated alumina devices contain a packed bed of activated alumina granules that range in size from 44 to 297 microns. Activated alumina is prepared by dehydrating aluminum hydroxide at a temperature between 550 and 1,100 degrees Fahrenheit, then grinding and screening it. The resulting activated alumina particles are very irregular and porous with a surface area between 15,560 and 95,560 square feet per ounce. The density and pore size also vary.

The bed of activated alumina granules is enclosed in a housing. As water passes through the device, certain contaminants are adsorbed to the activated alumina granules. The effectiveness of activated alumina depends on its ability to adsorb the targeted contaminant, the general water quality, and the design of the treatment device.

Activated alumina is capable of removing several contaminants from water. When more than one such contaminant exists in the untreated water, activated alumina preferentially adsorbs contaminants in the order listed in table 2.7. The ions are listed from the most strongly adsorbed to the most weakly adsorbed. Some research has reported that sulfate reduces the adsorption capacity of activated alumina for fluoride and arsenic, even though fluoride and arsenic are preferred over sulfate.

In addition to competition from other ions, the effectiveness of activated alumina depends on the chemical form of the contaminant to be removed. For example, two forms of arsenic, arsenate and arsenite, predominate between pH 6 and 9. Although a discussion of the various chemical forms of arsenic is beyond the scope of this publication, it is important to note that under certain circumstances, chlorinating the water before activated alumina treatment converts arsenic into the form most likely to be adsorbed by activated alumina.

Table 2.7 can also be used to evaluate the impact of additional contaminants on the effectiveness of activated alumina. Most importantly, the water pH should be less than 8.5. The pH defines the relative concentration of hydrogen ions (H^+) and hydroxide ions (OH^-). As pH increases, the concentration of hydroxide ions increases.

Table 2.7
Preferential order of ion removal for activated alumina

Ion	Common name
OH^-	Hydroxide
PO_3^{3-}	Phosphite
F^-	Fluoride
$Si(OH)_3O^-$	Orthosilicate
AsO_4^{3-}	Arsenate
$[Fe(CN)_6]^{4-}$	Ferricyanide
AsO_3^{3-}	Arsenite
CrO_4^{2-}	Chromate
SO_4^{2-}	Sulfate
$Cr_2O_7^{2-}$	Dichromate
NO_2^-	Nitrite
Br^-	Bromide
Cl^-	Chloride
NO_3^-	Nitrate
MnO_4^-	Permanganate
ClO_4^-	Perchlorate
CH_3COO^-	Acetate

Source: Data from Robert L. Lake, "Activated Alumina for POU/POE Removal of Fluoride and Arsenic," *Proceedings: Conference on Point-of-Use Treatment of Drinking Water,* U.S. Environmental Protection Agency Document EPA/600/9-88/012 (October 1987).

Note: Data are based on untreated water with a pH between 5.5 and 8.5.

Hydroxide ions are preferentially adsorbed by activated alumina when the pH exceeds 8.5, which will affect adsorption of other ions. For this reason, whether activated alumina is successful in removing fluoride or arsenic is pH-dependent. For fluoride, a pH between 5 and 6 is optimum. For arsenic, a pH of 7 is recommended. Pretreatment to reduce pH may be necessary for activated alumina to be effective (see discussion on pH adjustment beginning on page 37).

When the untreated water contains suspended solids, pretreatment with a 5-micron cartridge sediment filter is required to prevent clogging. Cartridge sediment filters are discussed begin-

ning on page 10. In addition, iron and manganese concentrations should be below levels in the U.S. Environmental Protection Agency (EPA) Secondary Drinking Water Standards (see appendix B for a listing of these standards).

Capacity

Flow rate and contaminant removal capacity are the two factors in determining the total capacity of an activated alumina device. Flow rate is dependent on the surface area of flow, the pore size of the activated alumina granules, and the available water pressure. As the area of flow increases, the flow rate increases, assu ming other factors are equal. Flow rate decreases as pore size decreases.

Household water pressure (about 30 to 60 pounds per square inch) is usually sufficient for producing adequate amounts of treated water. POU activated alumina units with a separate faucet generate approximately 1 gallon per minute of treated water at household water pressures. Larger POE devices may produce as much as 7 to 10 gallons per minute. If additional flow capacity is needed and a larger device is not available, use two devices in parallel.

The contaminant removal capacity depends mostly on the amount of alumina in the device. For example, a unit containing 4 ounces of alumina can treat approximately twice as much water as a unit containing 2 ounces of alumina.

Maintenance

Maintenance for an activated alumina device includes replacing the cartridge and monitoring treated water quality. Manufacturers may sugest guidelines for maintenance based on gallons of water treated or time the device is in operation. These recommendations give a rough estimate, but maintenance will vary depending on water quality and flow rate.

Since most of the chemicals removed by activated alumina are tasteless and odorless, test treated water once per month for the first few months after installation to determine the device's contaminant removal capacity. The capacity of the device is determined when the concentration of the contaminant in the treated water exceeds the safe level determined by EPA drinking water standards (see appendixes A and B).

After the capacity of the device is determined, develop a maintenance schedule based on gallons of water treated or time in operation. Of these two methods, monitoring based on gallons treated is preferred since water use can vary. Be aware that the concentration of any contaminants in groundwater may change, so occasional testing after the capacity is determined is still necessary to ensure that contaminant levels have remained constant. For more information on contaminant fluctuations in groundwater, see page 6 in this publication or see *Private Drinking Water Supplies: Quality, Testing, and Options for Problem Waters,* NRAES–47.

Activated alumina granules are regenerated by washing the granules with a strong base solution, which replaces the adsorbed contaminants with hydroxide ions. The granules are then washed with acid to remove the hydroxide ions and prepare the bed for use. Cartridges should be sent to water treatment professionals for regeneration since the chemicals used are hazardous.

Water treatment dealers should also backwash the activated alumina material immediately after installation and regularly as part of the regeneration service. Backwashing removes the finest activated alumina particles and dust from the filter material, which is necessary to prevent the activated alumina particles from cementing together. Cementing occurs when the device is unused for several days, and it reduces adsorption capacity.

Special Considerations

When activated alumina is used to remove a hazardous chemical, dispose of or regenerate the activated alumina carefully to avoid contaminating water supplies or landfills. Noncoliform bacteria can grow on the activated alumina medium, but coliform bacteria do not seem to grow in the filter.

Heat

Heating water is a common water treatment method, especially for disinfection purposes. Heat sources vary from an electric heating element to a wood fire. Boiling and distillation are two water treatment methods that use heat.

Boiling

Bringing water to a boil requires no special equipment, so it is a convenient and fairly inexpensive water treatment method. Boiling disinfects water during emergencies, on camping trips, or when a microbiologically safe water supply is unavailable.

Uses

Boiling water is a point-of-use (POU) treatment that kills bacteria—including disease-causing microorganisms such as *Giardia lamblia* and *Cryptosporidium parvum*. Boiling also vaporizes some volatile organic chemicals (VOCs) such as tetrachloroethylene, trichloroethylene, and carbon tetrachloride. It does not, however, reduce or eliminate nitrate, lead, or other minerals and metals. In fact, boiling may concentrate these contaminants, since some water evaporates while the contaminants are left behind.

Principles

Boiling water is the most widely available form of disinfection. Any heat source can be used, including electric stoves, gas stoves, camping stoves, wood fires, and microwave ovens.

Vigorously boiling water for three to five minutes will kill disease-causing microorganisms, inclu-ding *Giardia lamblia* cysts. *Cryptosporidium parvum* oocysts require thirty minutes of continual boiling.

Capacity

Boiling is an off-line system. The volume of water that can be disinfected at once is limited by the heat source and the size of the water vessel. It may take as long as fifteen minutes to boil only 1 gallon of water, after which the water has to be set aside to cool to drinking temperature.

Maintenance

Mineral scale accumulates in vessels used for boiling water. To dissolve the scale, soak vessels in a weak acid such as vinegar or lemon juice.

Special Considerations

Normally, boiled water is not dispensed through a tap. Boiling is an off-line treatment system that requires separate sterile storage for the treated water, as the distilled water can be recontaminated by pathogens if it is exposed to air. One major drawback to boiled water is that it may taste stale.

Distillation

Distillation is one of the oldest water treatment processes. Water is boiled and the resulting steam is collected and cooled in a separate chamber. The treated water is relatively free of many contaminants. Gener-ally, distillation is used to supply water only for drinking or special uses.

Home distillation units are usually electrical devices. They can be countertop units that are manually filled as water is needed, or they can be automatic and be connected to the household plumbing for continuous operation.

Uses

Distillation units are point-of-use (POU) devices that disinfect water, reduce the concentration of toxic metals, and remove some organic contaminants. A list of inorganic contaminants removable by distillation is given in table 2.8.

Distillation kills or removes microorganisms, including *Giardia lamblia* and *Cryptosporidium parvum*. Volatile organic chemicals (VOCs) may be difficult to remove, and pretreatment or posttreatment may be required. An alternative to distillation always exists. Refer to the water treatment key, table 1.3 on page 8, and appendixes A and B for a list of options.

Principles

The distillation process is illustrated in figure 2.19. A supply of feed water is diverted from the cold water line of the household distribution system, which allows continuous operation. The water is heated to boiling. (Most household distillation units use electricity as the heat source, but oil, wood, or any other heat source can be used.) The resulting steam flows into a condenser—a tube or coil cooled with cold water or air. The steam condenses in the cold tubing, and treated water is collected below the condenser.

Table 2.8
Inorganic contaminants removable by distillation

Aluminum	Lead
Arsenic	Mercury
Boron	Nitrate (as N)
Cadmium	Selenium
Chloride	Silver
Chromium	Sulfate
Copper	Vanadium
Fluoride	Zinc

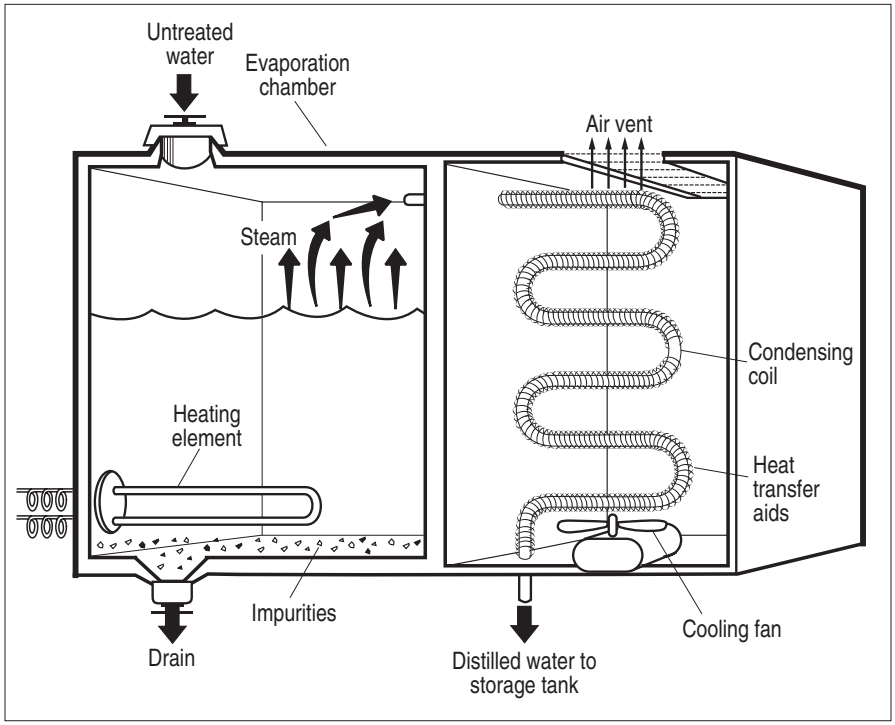

Figure 2.19
Air-cooled distillation device.
Reprinted with permission from *Water Technology* magazine.

One way to save water and energy is to purchase a distiller that uses diverted water as coolant before sending it to the distillation chamber. During the cooling process, the temperature of the coolant water increases, thus reducing the energy necessary for evaporation once the water reaches the distillation chamber. A maximum water temperature of 70 degrees Fahrenheit is suggested for such a design. Air is another coolant option that avoids waste.

Distillation removes all dissolved solids, regardless of their effects on water quality. Minerals in the dissolved solids give water its flavor, so distilled water is often flat and tasteless. Removing dissolved solids also makes the water aggressive, so the storage tank and other distiller components must be made of corrosion-resistant materials. Since distillation is generally a POU treatment, the household water distribution system need not be corrosion-resistant.

Manufacturers usually state minimum water quality parameters for the untreated water. Very high hardness levels or dissolved solids concentrations reduce the efficiency of the distiller. Dissolved solids precipitate in the boiling chamber and, over time, reduce the heat exchange efficiency between the heating element and the water. For more efficient distillation, pretreat excessively hard water (water containing more than 12 grains per gallon or 200 milligrams per liter hardness) with a water softener.

VOCs that vaporize at temperatures lower than the boiling point of water may pass through the condenser coil and become concentrated in the treated water. Preheating the water in a vented part of the distiller before it enters the boiling chamber will allow the VOCs to escape. The vapors must be vented to the outside so they do not accumulate in the home. If undesirable organic chemicals remain in the distilled water, posttreatment with an activated carbon device may remove them. Activated carbon is discussed on page 26.

A good distiller includes a water level sensor that shuts off the heat source if the boiling vessel runs dry. Others may have a temperature sensor to prevent overheating.

Capacity

The size of the boiling chamber, while it may dictate how often a distiller needs to be refilled, does not indicate the unit's production rate, which is usually stated in gallons per day. Production rates vary with the type of condensing system. Air-cooled devices typically produce 1 gallon of treated water for each gallon of untreated water. Water-cooled units may require 5 to 15 gallons of untreated water for each gallon of treated water. About four hours are required to produce 1 gallon of water.

Electricity requirements also vary. Portable units, which generally produce 3 to 4 gallons per day, typically have 500- to 700-watt heating elements. Larger units have heating elements of 1,000 to 1,500 watts and produce 8 to 12 gallons per day. Home units generally operate on 115 volts (normal household power). It takes about 800 watts of electricity to distill 1 quart of water in one hour (an equivalent measure is 0.8 kilowatt-hour per quart). Costs will vary based on the temperature of incoming water and system design, but the electrical costs for distilled water usually range from $0.25 to $0.33 per gallon.

A continuously operating, off-line distiller for home use should have a storage tank to hold treated water until it is needed. The storage tank capacity may provide an estimate of a distillation unit's capacity. Most tanks drain by gravity, but some may have a pump to deliver treated water to other locations.

Maintenance

Any water that remains in the distillation unit is concentrated with minerals and metals, so dispose of it carefully. Mineral deposits can be removed by adding a weak acid such as vinegar or lemon juice to the boiling chamber. It is important to keep mineral buildup on the heating element to a minimum, as it reduces heat transfer and results in higher energy costs. Buildup may also necessitate periodically replacing the heating element, although an individual element should last approximately three years.

How often to clean a distiller depends on the water quality—especially the hardness level. After installation, check the boiler chamber and heating element in continuously operating units on a weekly basis for scale accumulation. Check countertop units after each distillation cycle. Develop a regular maintenance schedule based on these initial observations.

For continuously operating distillation units, periodically draining or sending to waste part of the water from the boiling chamber may prevent solids from precipitating and may eliminate some solids that have already precipitated.

Special Considerations

Distillation units require electricity, although power usage can be decreased in units with automatic shutoff devices. Distillers also generate heat and can increase the temperature in a small room. Shock and fire hazards can be avoided by only using equipment approved by Underwriter's Laboratory. Such equipment is marked with the letters "UL."

Ultraviolet Light

Ultraviolet (UV) light rays—those that we get from sunlight—are known to have a strong germicidal ability. As is illustrated in figure 2.20, they have a longer wavelength than x rays and a shorter wavelength than visible light.

UV light has been used to disinfect water supplies for over seventy-five years, but only recently have home UV systems become available. Municipalities sometimes use UV instead of chlorination for disinfection to avoid the byproducts that chlorination may produce in the treated water supply.

The main advantage to UV treatment is that it disinfects water without the use of chemicals. Its main disadvantage is the lack of residual disinfection.

Uses

UV devices may be either point-of-use (POU) or point-of-entry (POE). UV light inactivates bacteria, viruses, and some cysts. It does not kill *Giardia lamblia* cysts or *Cryptosporidium parvum* oocysts, which must be re-moved by cartridge filtration (see page 10), precoat filtration (see page 18), boiling (see page 32), or distillation (see page 33). UV is not recommended if the untreated water has a coliform content exceeding 1,000 total coliforms or 100 fecal coliforms per 100 milliliters.

It is important to note that, although UV is an effective disinfectant, disinfection only occurs inside the unit—no residual continues to inactivate bacteria that survived or were introduced after UV treatment. If residual disinfection is necessary, chlorination (discussed on page 47) may be necessary in addition to or as an alternative to UV.

Principles

The typical UV device, illustrated in figure 2.21 on the following page, requires electricity and consists of a cylindrical chamber that houses a low-pressure mercury lamp. The lamp, which resembles a fluorescent lamp, produces the UV light in the range of 260 nanometers. (A nanometer is one billionth of a meter.) Most microorganisms are affected by radiation between 200 and 300 nanometers.

The lamp is encased by a quartz glass sleeve, which prevents the water from contacting the lamp and helps keep the lamp at an ideal operating temperature of 104 degrees Fahrenheit. Approximately 95 percent of the radiation passes through this glass sleeve and into the untreated water. The untreated water either flows in a thin film over the sleeve, or it flows through quartz glass tubing that is spiraled around the lamp. The latter design allows for a longer contact time between the UV light and the untreated water.

UV treatment does not remove organisms from water—it merely inactivates them by inhibiting DNA replication. Lamp intensity, contact time, and general water quality determine the effectiveness of the process.

The lamp intensity is reported as microwatt seconds per square centimeter. Water quality agencies can recommend a lamp strength based on water quality and the microbes targeted for destruction. A general recommendation is to have a lamp intensity no less than 16,000 microwatt seconds per square centimeter. More than 20,000 microwatt seconds per square centimeter is preferable. Most devices provide a lamp intensity of 30,000 to 50,000 microwatt seconds per square centimeter. A flow control device on the UV unit can regulate the contact time.

The UV unit may be the last device in a treatment system. Particulates and turbidity affect light transmission into the microorganisms and must be removed with a cartridge sediment filter (see page 10) prior to UV disinfection. Color resulting from decaying plant matter must be removed with an activated carbon device (see page 26) prior to UV disinfection. When untreated water has high mineral levels,

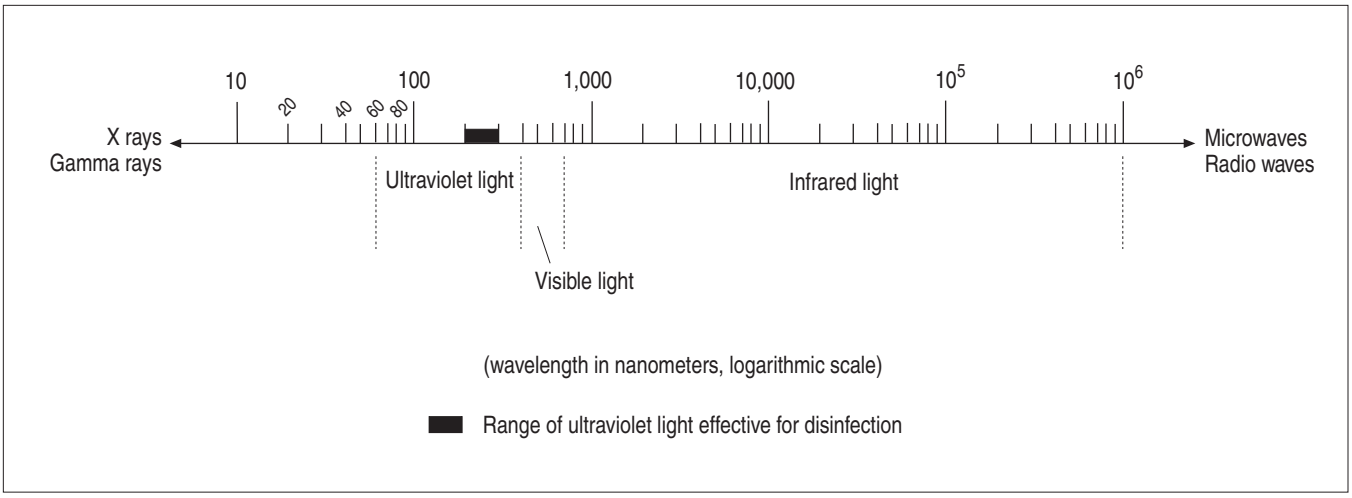

Figure 2.20
Ultraviolet light for disinfection.

pretreatment with a water softener (see page 41) or phosphate injection system (see page 57) may be necessary to prevent minerals from building up on the lamp.

A UV unit should be located as close as possible to the point of use, as any part of the plumbing system could be contaminated with bacteria. Before using a UV system for the first time, disinfect the entire plumbing system with chlorine.

Capacity

There is a limit to the numbers of bacteria that can be treated with UV. An upper limit for UV disinfection is 1,000 total coliforms per 100 milliliters or 100 fecal coliforms per 100 milliliters.

UV systems may have a flow rate capacity from 0.5 gallon per minute to several hundred gallons per minute. Household water requirements dictate the level of treated water needed. Table 1.1 on page 5 can help estimate water usage for a particular household.

Maintenance

Since UV light must contact bacteria to kill them, the housing for the light source must be kept clean. Commercial products are available for rinsing the unit and removing any film that forms on the lamp housing. An overnight cleaning with a solution of 0.15 percent sodium hydrosulfite or citric acid also effectively removes such film. Some units, such as the one pictured in figure 2.21, have wipers to help clean the lamp housing.

UV lights do not burn out—they gradually lose power with use. Therefore, replace the lamp at least once per year.

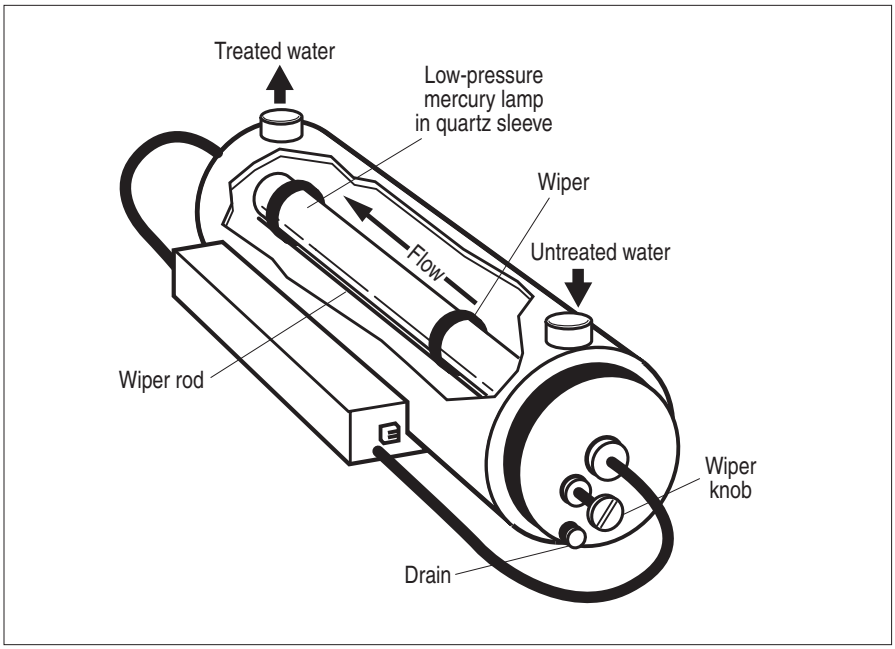

Figure 2.21
Ultraviolet treatment device.
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It is not uncommon for a new lamp to lose 20 percent of its intensity within the first one hundred hours of use. However, the remaining intensity will last for the next several thousand hours.

Some UV units are equipped with UV emission detectors to warn users when the unit needs cleaning or when the light source is failing—an important feature to ensure a safe water supply. A detector that emits a sound or shuts off the water flow is preferable to one with a warning light. Detectors should not supplant annual replacement of the light source or regular cleaning of the lamp housing.

UV-treated water should be monitored monthly for at least the first six months after installation. Monitor for coliform and heterotrophic bacteria. If these microorganisms are found to be present in the treated water, check the lamp intensity and shock chlorinate the entire plumbing system. For a detailed description of shock chlorination, see page 49.

UV systems are designed for continuous operation. They should be shut down only when treatment is not needed for several days. It usually takes a few minutes for the lamp to warm up again following shutdown. To remove any untreated water from the system following a period of disuse, thoroughly flush the entire plumbing system.

Special Considerations

It is important to remember that UV provides no residual disinfection. If the contact time is insufficient or if suspended solids shield the microorganisms, the microorganisms will still be a health hazard. Storing UV-treated water could result in recontamination.

3 | *Chemical Treatment*

Chemical treatment involves adding a solid, liquid, or gas to water to improve water quality. Solids used in water treatment include salt, limestone, phosphates, iodine, and potassium permanganate. Liquids include solutions of chlorine and soda ash. Air and ozone are the primary gases used in home chemical treatment systems.

Chemicals have varied effects on untreated water. Some change the pH; others exchange contaminants for less objectionable substances. Chemicals called sequestering agents "tie up" or inactivate a contaminant. Air may be used to vaporize contaminants or oxidize certain dissolved minerals.

pH Adjustment

The acidity or alkalinity of water is measured using the pH scale, which is illustrated in figure 3.1 on the following page. The scale ranges from 0 to 14. A pH of 7 is neutral. When the pH is greater than 7, the water is alkaline; when it is less than 7, it is acidic. The addition of an acid solution to water lowers the pH, whereas the addition of a base increases the pH.

Drinking water should have a pH between 6.5 and 8.5. If the pH is too low, water may corrode plumbing; if it is too high, water may have a "soda" taste and scale is more likely to form in plumbing.

Certain water treatment methods, such as chlorination, require water to be in a certain pH range for treatment to be effective. Chemicals that are either injected into or dissolved in the water can adjust pH. Monitoring pH before and after treatment is easy with test kits or pH paper.

The presence or absence of carbon dioxide affects acidity. When carbon dioxide is dissolved in water, it forms carbonic acid and makes water acidic, unless offsetting levels of bicarbonate alkalinity neutralize the acidity.

Neutralizing Filters

A neutralizing filter is a very simple treatment device that raises the pH of water by adding a neutralizing material. The neutralization process may increase water hardness, however.

Uses

Neutralizing filters are in-line, point-of-entry (POE) devices that raise water pH to near neutral (pH 7), which reduces or eliminates corrosion problems. Calcium carbonate effectively treats water with a pH greater than 6; synthetic magnesium oxide effectively treats water with a pH less than 6.

Principles

During neutralization, acidic water flows through a tank filled with granular calcium carbonate (limestone), crushed oyster shells, marble chips, or a synthetic magnesium oxide medium. The neutralizing

material dissolves, raising the water pH. Figure 3.2 illustrates the process.

In the case of calcium carbonate, the carbonate ion neutralizes the acidity while the calcium ion remains in solution. This dissolved calcium may create hard water problems. Magnesium from synthetic magnesium oxide may create similar problems. The resulting hardness level depends on the pH and the contact time between the neutralizer material and the untreated water and may get as high as 120 milligrams per liter. If hard water becomes a nuisance, the neutralizing filter should be followed by a water softener. Water softeners are described later in this chapter beginning on page 41. NRAES–47, *Private Drinking Water Supplies: Quality, Testing, and Options for Problem Waters,* contains additional information on water hardness.

Capacity

How much neutralizer a filter consumes depends on the acidity of the water and the contact time between the neutralizer and the untreated water. The amount consumed can be estimated by a water treatment professional based on information in a water test.

Because the neutralization process takes time, the rate of water flow through the device is crucial to complete neutralization. In general, the flow rate should be no faster than 3.0 gallons per minute per square foot of filter bed area.

A bed depth of 32 to 36 inches is necessary to provide adequate contact time. Shallower bed depths will result in incomplete neutralization.

Maintenance

Neutralizing material must be added every few weeks or months to replace the dissolved material. Backwashing can eliminate particles that become trapped in the medium. Because the neutralizing material can be very dense, backwash for at least ten minutes at a

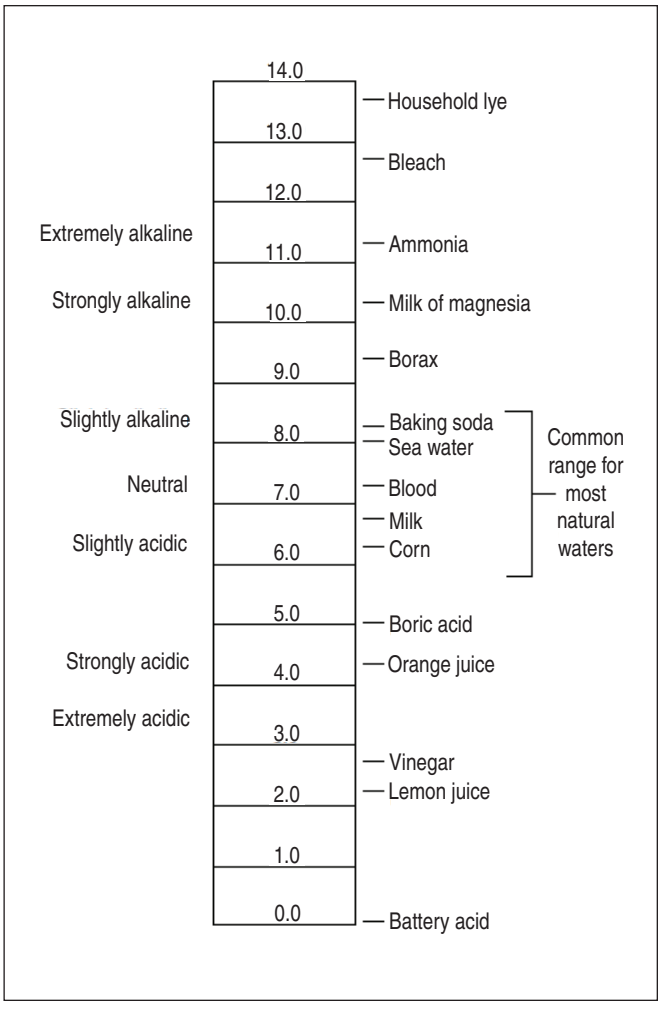

Figure 3.1
The pH scale.

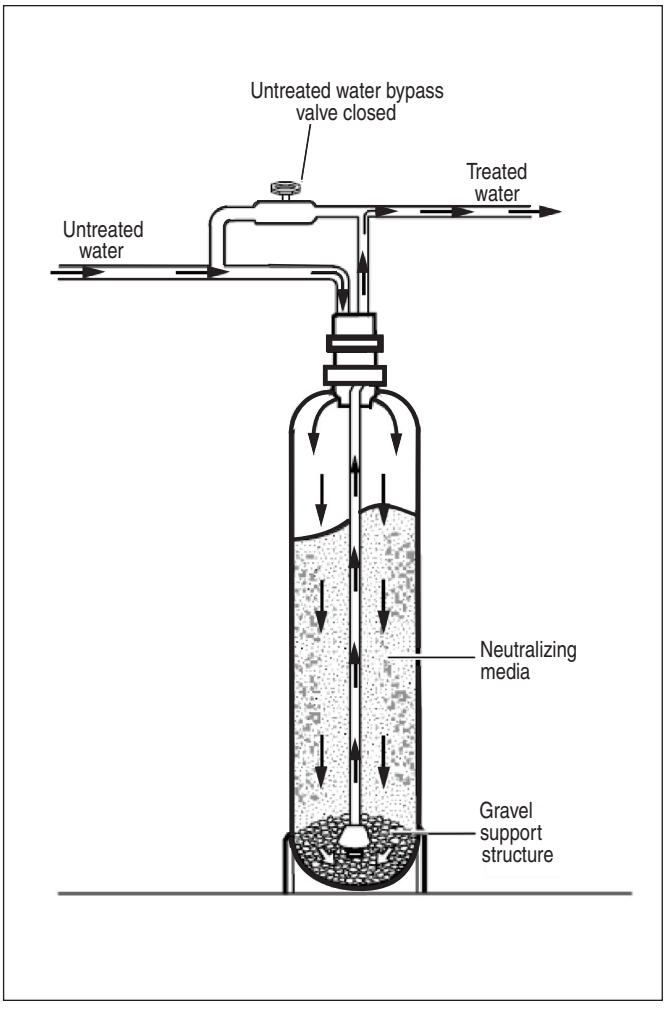

Figure 3.2
Neutralizing filter components and operation.

rate of at least 6 gallons per minute per square foot of bed area. A longer backwash time may be required for high-iron, low-pH waters. To reduce fouling and decrease the need for backwashing, remove particles before water enters the filter (see the section on mechanical filtration beginning on page 9).

Special Considerations

The biggest drawback to neutralizing filters is that they may cause or in crease water hardness. If the hardness is subsequently treated with a water softener, the softener will replace the hardness minerals with sodium, which may be unsuitable to persons on a low-sodium diet. In addition, the calcium carbonate material in neutralizing filters is finely ground and may cause significant water pressure loss.

Neutralizing filters are normally in stalled after the pressure tank, so neither the pressure tank nor the well pump is protected against corrosion. When the flow rate is high, a liquid injection system (described in the next section) may be better than a neutralizing filter, as it is installed before the pressure tank and thus provides corrosion protection to the tank and the plumbing system.

Soda Ash/Sodium Hydroxide Injection

Soda ash (sodium carbonate) and sodium hydroxide, when injected into a water system, raise the pH, thus reducing corrosion problems. Unlike neutralizing filters, injection systems do not cause hardness problems in treated water.

Uses

Injection systems are point-of-entry (POE) systems. Soda ash and sodium hydroxide raise the pH of water to near neutral, which reduces or eliminates corrosion.

Principles

A corrosion-resistant chemical feed pump, adjusted to achieve the desired pH, injects a solution of soda ash or sodium hydroxide into the water system. Figure 3.3 illustrates the process. The feed rate should be adjusted until the pH in the tap farthest from the injection point is 7. If a well supplies the water, the solution should be fed into the well to protect the well casing and pump from corrosion.

The amount of chemical needed depends on the carbon dioxide content of the untreated water. For complete neutralization, each milligram of carbon dioxide per liter of water requires at least 2.5 milligrams per liter soda ash or 0.85 milligram per liter sodium hydroxide. If the water needs to

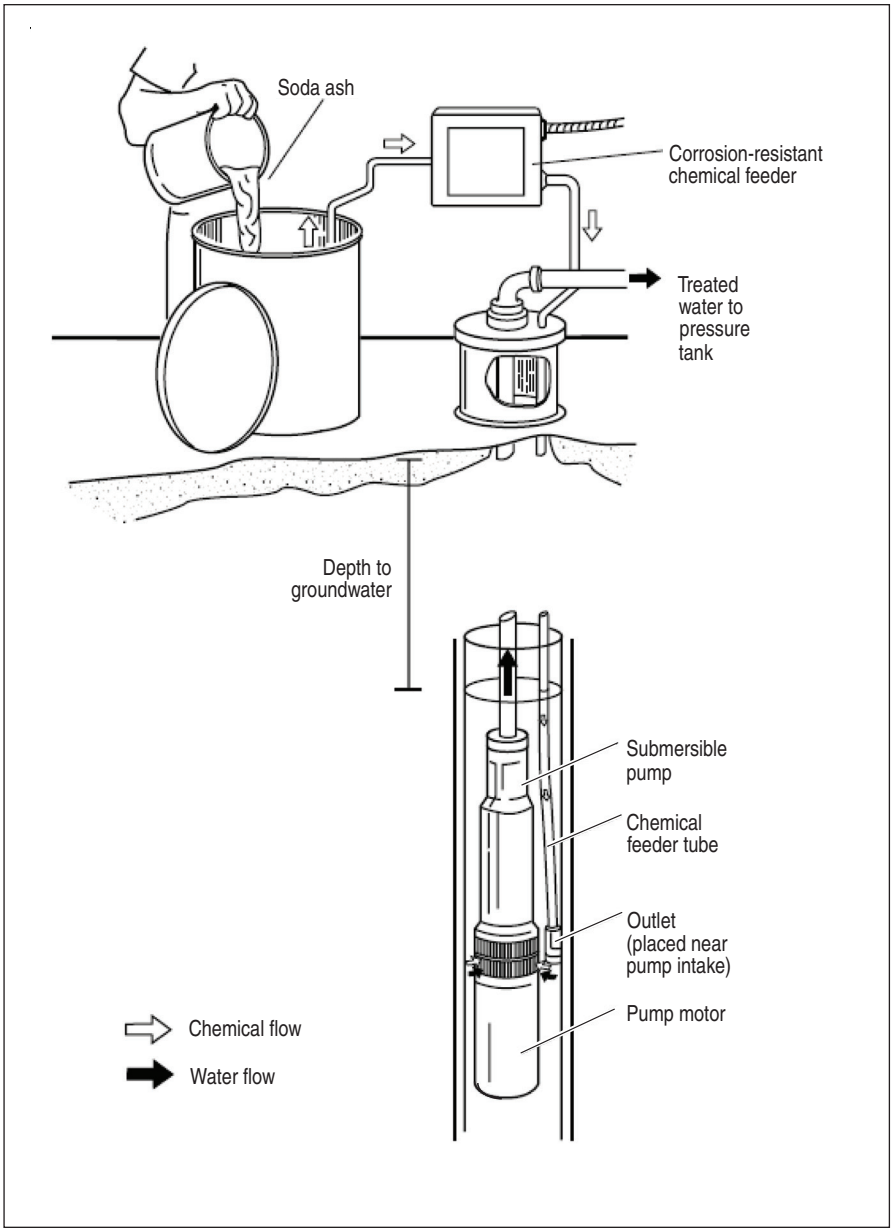

Figure 3.3
Soda ash injection.

Adapted from *Planning for an Individual Water System,* Fourth Edition, American Association for Vocational Instructional Materials, ©1982.

be disinfected as well as neutralized, dual treatment is possible by adding a chlorine (sodium hypochlorite) solution along with the neutralizing chemical.

Capacity

Soda ash and sodium hydroxide injection systems can treat water with a pH as low as 4. Carbon dioxide readings are too complicated to make on-site, so determine the soda ash or sodium hydroxide dose through trial and error. Begin by mixing 0.25 pound of neutralizer with 1 gallon of water and injecting the solution into untreated water. Use a pH test kit to determine the resulting pH. Increase the solution concentration if the pH is still too low. A typical injection system uses a solution of 0.5 to 1 pound of neutralizer per 1 gallon of water.

Maintenance

As with all chemical feed systems, the chemical feed pump must be maintained and the chemical storage tanks refilled. Soda ash, the preferred chemical, is safer to handle than sodium hydroxide. Screens and filters should be periodically checked and cleaned if necessary.

Special Considerations

Use caution if using sodium hydroxide. If adding it manually, maintain good ventilation to avoid breathing vapors and add the chemical to the water slowly with complete mixing. Wear protective rubber gloves and goggles to avoid getting the chemical on the skin or in the eyes. Sodium hydroxide is often sold in 1-gallon plastic containers that include a deposit to encourage the user to return the container to the supplier. This prevents the container from being used for other purposes. Transport sodium hydroxide carefully, and store it in a cool, dry place away from flammable materials.

Individuals on a low-sodium diet should consult a doctor before installing an injection system. Use manufacturer specifications to compare sodium levels in the treated water to levels consumed from other sources in the diet. Potassium hydroxide may be substituted for sodium hydroxide but it is currently more expensive.

Acid Injection

Acid injection reduces the pH of wa ter, which eliminates a "soda" taste, improves the effectiveness of chlori nation, or both. Water with a pH above 9 can corrode metals such as brass, copper, zinc, aluminum, and iron, so acid injection reduces the potential for corrosion.

Uses

Acid injection is an in-line, point-of-entry (POE) system. It reduces the pH of water to near neutral, thus reducing or eliminating corrosion problems and soda tastes and improving the effec tiveness of certain treatment processes.

Principles

A chemical feed pump made from corrosion-resistant materials injects a 5 percent solution of acetic acid (white vinegar) into high-pH water. Citric acid and alum can be used instead, although they are more expensive. Weak solutions of hydrochloric acid or sulfuric acid also lower pH but they are more hazardous and require special handling. They are recommended, however, if the pH of the untreated water is 11 or higher. *When diluting acid solutions, always add acid to water slowly, never add water to acid.* After adding the acid solution, the feed rate should be adjusted so that the pH at the tap farthest from the injection point is 7.

Maintenance

As with all injection systems, the pump must be maintained and the chemicals refilled. Wear goggles and chemical protective clothing when handling acid solution.

Special Considerations

Chemicals used in acid injection systems should be handled carefully and stored in clearly marked containers, out of the reach of children. Be sure to thoroughly examine manufacturers' recommendations before purchasing an acid injection system or the necessary chemicals.

Ion Exchange

Ion exchange replaces unwanted minerals in water with less objectionable ones. The exchange occurs in a fiber glass tank or plastic-lined steel tank filled with a special ion exchange material—either a commercial resin, which is a petrochemical compound shaped into beads, or a synthetic zeolite, which is a crystalline formulation of aluminates and silicates.

The appropriate exchange material to use depends on the untreated water quality and the desired water quality. Certain exchange materials deteriorate in the presence of chlorine or other oxidants. Zeolites are more able to reduce the concentration of iron and manganese than are commercial resins.

Typically, the exchange material is prepared by exposing the beads to a salt solution. As untreated water passes through the device, the undesired ions are exchanged for ions on the exchange material.

The two types of ion exchange units are water softeners and anion exchange devices. Water softeners remove cations (positively charged minerals such as calcium and magnesium) and replace them with sodium. Anion exchange devices remove anions (negatively charged ions such as arsenic and nitrate) and replace them with chloride.

Mixed media ion exchange units remove both cations and anions. A typical mix would be 60 percent cation exchange material and 40 percent anion exchange

material. These units usually must be regenerated at a central processing plant. Two-bed deionizers, which use separate cation and anion vessels, can be backwashed to remove trapped particles.

Water Softening (Cation Exchange)

Water softeners are the most widely used home water treatment devices. They remove minerals that form scale on water heaters and soap film on sinks. Water softening is sometimes referred to as water conditioning.

Uses

Softeners are in-line, point-of-entry (POE) devices that remove hardness minerals. Softeners also remove barium, radium, and small amounts of dissolved iron and manganese.

Principles

Water softeners consist of a corrosion-resistant tank that is filled with resin beads that are saturated with sodium. The resin prefers calcium and magnesium (the principle components of hardness) over sodium. As water passes over the beads, sodium is released and calcium and magnesium are adsorbed. Figure 3.4 illustrates this process. A distributor or baffle disperses the untreated water throughout the resin. This assures that all the untreated water contacts the exchange material instead of channeling, or passing directly through the column without contact.

Some softeners include a brine tank for holding dry salt pellets and for mixing brine solution. Brine is the concentrated salt (sodium chloride) solution used in regeneration. The brine tank is usually made of a corrosion-resistant material such as fiberglass or plastic. A brine tank is shown in figure 3.5.

Water softeners may include additional softener tanks (in which case the system is called a twin-alternating or parallel system); additional valves for regenerating the resin; and switches, flowmeters, or time clocks for automatic or semiautomatic regeneration. Flowmeters measure gallons of water treated instead of time the unit is in operation. If using a softener equipped with a flowmeter, it may be wise to pretreat the water with a 5-micron sediment filter to prevent clogging.

Capacity

Water softeners can either treat all the water in the house or only the water leading to the hot water heater. Before installing a softener, consider the proposed uses of the treated water. In some cases, only the hot water should be softened to reduce scale formation in the water heater and hot water pipes. In other cases, water used only for cleaning, bathing, and laundering should be softened to prevent detergent films from forming. Water used for drinking and cooking should not

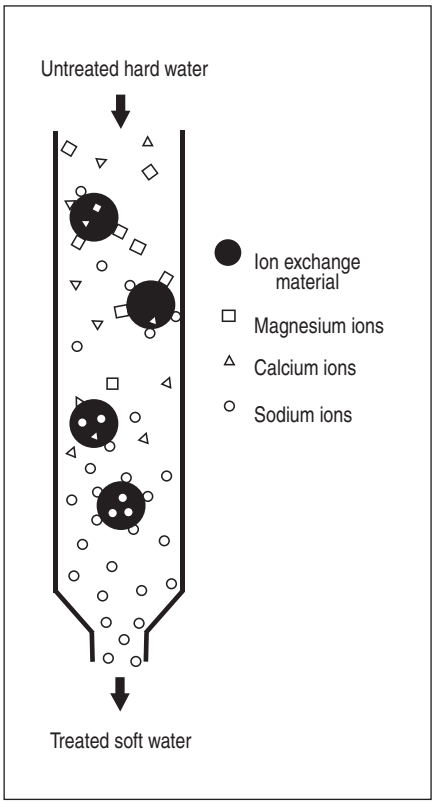

Figure 3.4
The softening process.

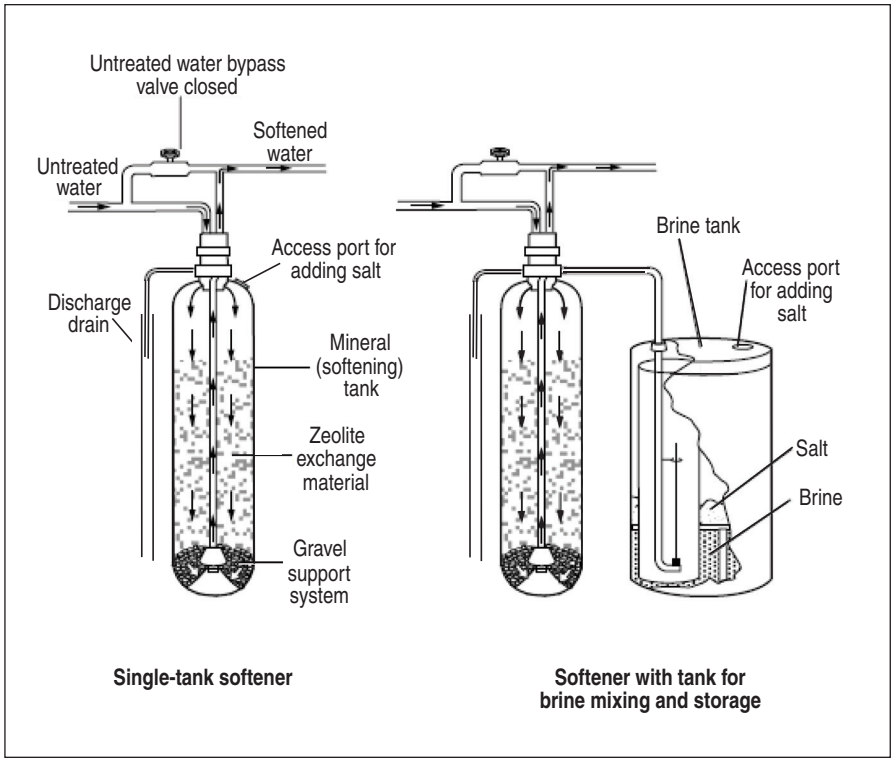

Figure 3.5
Two types of water softeners.

need to be softened, nor should water used outdoors. Toilet water should be softened only if the softener is being used to remove low levels of iron, which may cause staining. A plumber or water treatment specialist can help determine the best installation scheme for a particular household.

The appropriate size of softener depends on the hardness level, daily water use, and flow rate. A water-testing laboratory can determine the hardness level, which is reported as either grains per gallon or milligrams per liter as calcium carbonate. One grain per gallon is equal to 17.17 milligrams per liter.

The hardness levels classified in table 3.1 are from the American Society of Agricultural Engineers (ASAE). The amount of calcium and magnesium in water is reported as if it were all present as calcium carbonate, which allows total hardness to be reported as one number. Both calcium and magnesium ions may result from a variety of dissolved chemical compounds. For instance, calcium may occur as calcium bicarbonate or calcium chloride.

Table 1.1, "Approximate daily water needs for home and farm," can help estimate daily water use (see page 5). Once hardness and daily water use are known, daily water hardness can be calculated with the formula below. Daily water hardness can help deter mine the softener size needed.

$$\text{daily water hardness} = \text{\# people in household} \times \text{daily water use per person} \times \text{water hardness}$$

Example:

$$\text{daily water hardness} = 4 \text{ people} \times 50 \text{ gallons/person} \times 15 \text{ grains/gallon}$$

$$\text{daily water hardness} = 3{,}000 \text{ grains}$$

The system flow rate depends on the demands of all the fixtures and appliances used in the home. The softener's flow rate will not be greater than the water pump's flow rate; therefore, use the pump capacity to select an appropriately sized softener. For example, according to table 3.2, if the pump capacity is 10 gallons per minute, a 30,000-grain softener would be used.

Other cations such as iron will also affect capacity. Manufacturers may provide recommendations for maximum dissolved iron levels. Use table 3.3 to determine the additional bed volume required for various dissolved iron concentrations. Water softeners can only be used for dissolved iron (also called clear water iron). If the water has a red tint, or if rust-colored par-

Table 3.1
Water hardness levels (hardness as calcium carbonate—$CaCO_3$)

Classification	Grains/gallon	Milligrams/liter
Soft	0.0 to 3.5	0 to 60
Moderately hard	3.5 to 7.0	61 to 120
Hard	7.0 to 10.5	121 to 180
Very hard	More than 10.5	More than 180

Source: Reprinted from *ASAE Standards 1994,* ASAE Standard S339, The American Society for Agricultural Engineers.

Table 3.2
Hardness limits

Recommended flow rate (pump capacity) (gallons/minute)	Softener capacity (grains)	Maximum hardness (grains/gallon)	Bed volume (cubic feet)
3 to 4	10,000	20	0.3
5 to 6	15,000	25 to 30	0.5
7 to 8	21,000	40 to 50	0.7
10 to 12	30,000	60 to 70	1.0
15 to 18	45,000	75 to 90	1.5

Source: Jay Lehr, Environmental Education Enterprises, Columbus, Ohio.

Table 3.3
Additional bed volume required for iron removal

Clear water iron limit [a] (milligrams/liter)	Additional bed volume required (cubic feet)
0.5	0.3
2.5	0.5
4.0	0.7
5.0	1.0

Source: U.S. Department of Agriculture, Agricultural Research Service and Extension Service. *Water-Quality Improvements for Farmstead and Rural Home Water Systems,* Farmers Bulletin Number 2274 (1984).

[a] Clear water is water containing only dissolved iron.

ticles can be seen in the water, the iron present is not dissolved.

Another way to compensate for potential iron fouling is to increase the regeneration frequency. See page 44 for an equation for regeneration frequency.

Maintenance

When the softener has exchanged all of its available sodium, its exchange capacity is exhausted. In a process called regeneration, brine is passed through the bed to release the adsorbed calcium and magnesium ions and restore sodium to the resin. The released ions are carried away in the wastewater. This process is illustrated in figure 3.6. The distributor or baffle prevents resin from being washed out of the softener.

The regeneration process can be manual, semiautomatic, or fully automatic. Manual systems require the homeowner to initiate the regeneration and rinsing cycles as well as the return to service. With semiautomatic systems, homeowners must initiate the regeneration cycle but the softener controls everything else. Fully automatic softeners are equipped with a timer that automatically starts the regeneration cycle and every step there after; regeneration is usually done during a period of low water use.

A fourth type of regeneration, demand-initiated regeneration (DIR), automatically regenerates the softener. The system initiates regeneration based on the gallons of water used, a change in the electrical conductivity of the resin bed, or a change in treated water hardness.

The two styles of regeneration are cocurrent and countercurrent. Cocurrent regeneration passes the brine solution in the same direction as the water flow when the unit is softening, which may result in leakage. Cations at the bottom of the resin column are not completely removed, so when the unit begins treating water, these cations leak into the softened water. Since the regeneration flow is in the same direction as service flow, trapped particles will not be removed.

Countercurrent regeneration is more expensive than cocurrent regeneration. In this style, brine flows opposite to the water flow and the top of the resin column is not fully regenerated. When the unit begins treating water, cations remaining at the top of the column are removed lower on the column, and leakage is not a problem. With countercurrent regeneration, the tank should be designed to minimize bed expansion. If the bed expands by more than

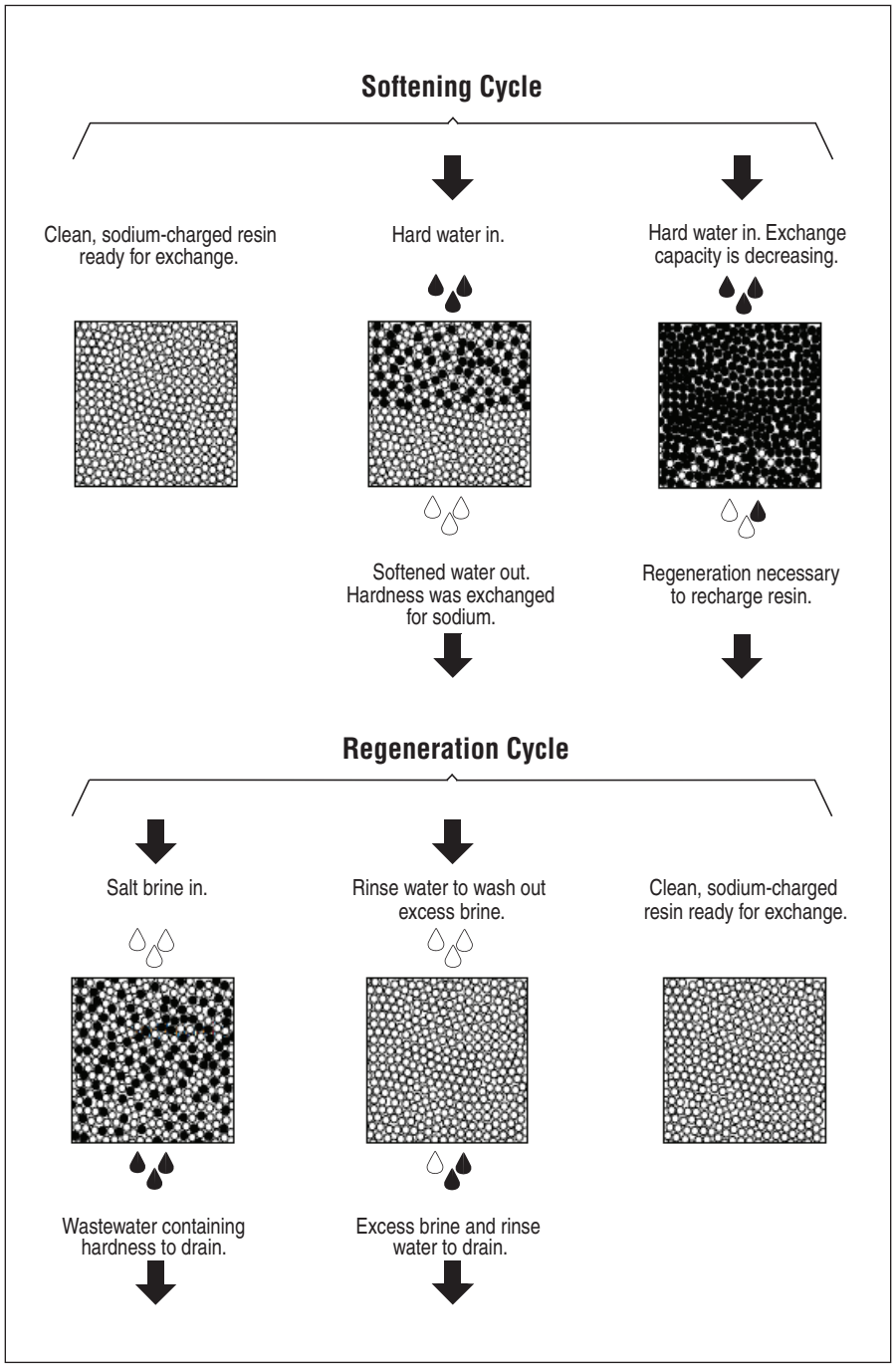

Figure 3.6
Water softening and regeneration cycles.

5 to 10 percent, the resin will not be fully regenerated. This will increase the regeneration frequency. Cocurrent and countercurrent regeneration are illustrated in figure 3.7.

To determine the regeneration schedule, meter the gallons of treated water or the pH or conductivity of the treated water (a change occurs when the exchange capacity is exhausted), or calculate a typical time interval between each regeneration (usually six to four teen days). The latter method is the least exact, because it does not account for changes in water use.

Estimate the regeneration frequency by dividing the softener capacity by the amount of hardness removed daily (see page 42 for an equation for hardness removed daily).

$$\text{regeneration frequency} = \frac{\text{softener capacity}}{\text{hardness removed per day}}$$

Example:

$$\text{regeneration frequency} = \frac{\text{30,000-grain softener}}{\text{3,000 grains per day}} = \text{every 10 days}$$

Many different types of salt effectively regenerate the resin column. All salt supplies used to regenerate exchange resin must be refilled periodically. Rock salt is inexpensive, but it can be quite dirty and may add sediment to the softener. Purified salt is less likely to foul equipment. It comes in granulated, pellet, and block forms. Sodium chloride is the most common salt used in water softeners.

To determine the annual salt consumption, multiply the salt dosage required per regeneration (recommended by the manufacturer) by the number of regenerations per year (365 divided by the days between regenerations).

$$\text{annual salt} = \text{salt dosage per regeneration} \times \frac{365}{\text{days between regenerations}}$$

Example:

$$\text{annual salt} = \text{15 pounds salt} \times \frac{365}{\text{10 days}} = \text{547 pounds}$$

Potassium chloride can be used instead of sodium chloride to avoid elevated sodium levels in softened water. However, potassium chloride is more expensive and somewhat harder to find than sodium chloride. In addition, potassium adheres more strongly to the resin, so it may reduce the exchange efficiency. The water treatment industry views potassium chloride as a possible substitute for sodium chloride when the latter is not allowed for health-related or environmental reasons. Potassium chloride is not thought to be a feasible replacement for sodium chloride in all situations.

Regeneration does not completely restore the exchange capacity of the resin, so the softener's effectiveness will gradually decrease. Exhausted resin should be replaced. Another alternative is to ask water treatment professionals for guidance on improving exchange capacity with a strong acid or base solution.

Sediment can clog the exchange resin, nozzles, and orifices in softeners and reduce regeneration effectiveness. Normal countercurrent regeneration may not be enough to remove sediment from the softener, so prevent sediment buildup by pretreating water to remove turbidity, sediment, or particles of iron, manganese, or sulfur. (See the section on mechanical filtration, page 9, for possible pretreatment options.) During cocurrent regeneration, opening the tank and stirring the resin beads with a rod or broom handle will dislodge trapped particles.

Iron fouling is a serious problem in water softeners. Water softeners remove dissolved iron, but once this iron is exposed to air or chlorine, it oxidizes and forms a solid that is trapped in the softener. If a softener becomes iron-fouled, commercially available products containing either sodium hydrosulfite or polyphosphates effectively clean the resin. (It is important to note that phosphate use is banned in states bordering the Great Lakes and may be banned in other areas. Consult a local cooperative extension office or health department for information on possible local regulations.)

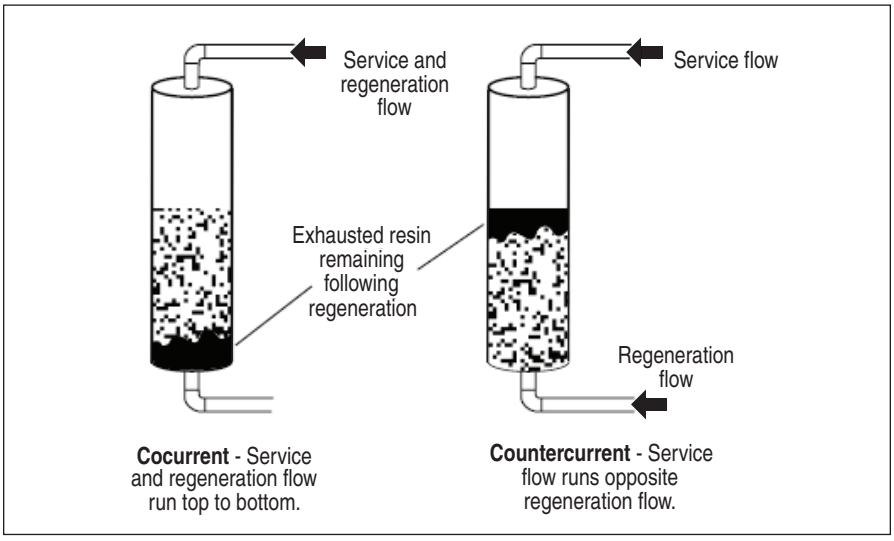

Figure 3.7
Two styles of softener regeneration.

Because badly fouled exchange material is so difficult to clean, prevention is the best maintenance procedure. To lessen or help prevent iron fouling, prefilter oxidized iron particles before softening. (See the section concerning mechanical filtration beginning on page 9.) Another option is to use salt compounds that contain an iron-cleaning chemical. These compounds are commercially available and clean the exchange bed with each regeneration.

Slime such as iron bacteria sometimes forms in softeners. To prevent this buildup, disinfect water before it enters the softener. If using chlorine for disinfection (see page 47), remember that chlorine oxidizes iron to a solid, which can lead to iron-fouling. If this happens, use filtration in addition to chlorination before water enters the softener.

The softener exchange material can be periodically disinfected with chlorine bleach. High levels of chlorine can destroy certain resins, so use care when disinfecting the exchange material. Consult a water treatment professional for guidance. Chloramine also disinfects exchange material and has a lesser impact on the resin than chlorine bleach.

Hydrogen sulfide, a noxious gas, is a problem in a softener only if the hydrogen sulfide mixes with iron, manganese, or copper. The resulting reaction creates a black deposit of metallic sulfide. If this occurs, remove any hydrogen sulfide before the water contacts the exchange material. Consult the water treatment key, table 1.3 on page 8, for methods to remove the gas. Common softener cleaners will not clean a bed fouled by hydrogen sulfide; hydrochloric acid should be used instead.

Special Considerations

Regeneration places an additional hydraulic load on a septic system. It takes approximately 50 gallons of water (equal to a washing machine load) to regenerate a softener.

Certain states prohibit disposing of brine in an on-site sewage system. Exercise caution when disposing of regeneration water from a softener used for removing radium, as the water is radioactive. Check with local health officials for information on local regulations.

Salt bridging, a process in which salt forms bridges between exchange material beads, may occur when condensation collects in the resin tank. Salt bridges are similar to the clumps that form in salt shakers when salt is damp.

Whether to soften water is a matter of personal preference. While softening does reduce deposits in water heaters and other components of the water distribution system, it also adds sodium to water. About 8 milligrams per liter sodium is added for every grain of hardness the softener removes (or about 1 milligram per liter sodium for every2 milligrams per liter hardness). This amount is small when compared to the salt in a typical daily diet; nevertheless, persons on a low-sodium diet should consult a physician before drinking softened water. If necessary, a bypass water line can be installed at the kitchen sink to provide unsoftened water for drinking and cooking.

Anion Exchange

Anion exchange operates on the same principle as cation exchange. The only difference is that anion exchange devices adsorb anions such as nitrate and sulfate instead of cations such as calcium and magnesium.

Uses

Anion exchange devices can be either point-of-entry (POE) or point-of-use (POU). They reduce the concentrations of sulfate, nitrate, and arsenic in water. POU units remove hazardous chemicals such as nitrate from drinking and cooking water only and can be connected to a single tap. POE devices treat water for the whole household.

Principles

The surface of anion exchange resin beads is covered with chloride. As water passes through the device, the resin adsorbs anions such as sulfate and nitrate and releases chloride into the water. Any naturally occurring bicarbonate in the water is also exchanged for chloride, which makes the water corrosive (bicarbonate keeps the pH neutral).

The simplest anion exchange unit consists of a tank to hold the resin and appropriate plumbing for untreated and treated water. The tank should be corrosion-resistant because regeneration uses concentrated salt solutions. Some units may have a separate tank for brine mixing and storage, additional valves for regenerating the exchange resin, and detectors that monitor the nitrate concentration in treated water.

Resins give preferential treatment to certain ions. The order of adsorption depends on the characteristics and concentration of each ion in the water. Table 3.4 lists the order in which most resins adsorb different anions. Typi-

Table 3.4
Order in which anion exchange resin adsorbs anions

Ion	Common name
CrO_4^{2-}	Chromate
SO_4^{2-}	Sulfate
SO_3^{2-}	Sulfite
HPO_4^{2-}	Phosphate
NO_3^-	Nitrate
NO_2^-	Nitrite
Br^-	Bromide
Cl^-	Chloride
HCO_3^-	Bicarbonate
$HSiO_3^-$	Bisilicate
OH^-	Hydroxide
F^-	Fluoride

Source: Adapted with permission from *Water Technology* magazine.

cally, resins prefer sulfate over nitrate; in fact, sulfate pushes nitrate off the resin column if the two are competing. This process, known as nitrate dumping, is illustrated in figure 3.8.

Most resins are ineffective in removing nitrate if sulfate is also present in the water. Nitrate-selective resins rearrange the preference order: nitrate is adsorbed first, then sulfate, then chloride, then bicarbonate. Nitrate-selective resins push sulfate off the exchange material if the two ions are competing but do not dump nitrate when the resin capacity is exhausted. These resins are not yet widely available in the United States, however.

Capacity

Before installing an anion exchange unit, consider the requirements of the treatment system. Nitrate and sulfate are odorless, colorless, and nonstaining, so only drinking and cooking water may require treatment.

The amount of water an anion exchange device can treat depends on the contaminant being removed. If removing nitrate, the removal capacity will depend on both the nitrate and the sulfate concentration in the water, as anion exchange resins preferentially adsorb sulfate. When all the exchange sites are filled, the sulfate will bump nitrate from the resin and into the treated water.

The size of the unit needed and the time between regenerations also depends on daily water use and flow rate. Consult a water treatment professional for assistance in selecting a device.

Maintenance

When all the chloride has been exchanged, the resin beads are said to be exhausted. They are regenerated with brine. The brine solution releases the adsorbed contaminants and replaces them with chloride. The released an ions are washed out with the waste brine. Maintaining an anion exchange unit also includes stocking the salt supply.

Anion exchange treats water containing contaminants that can have negative health effects. It is crucial to monitor the treated water for these contaminants to verify that the unit is working properly. Home test kits are available to estimate nitrate and sulfate concentrations. If testing shows that contaminant concentrations exceed an acceptable level, regenerate the unit.

Special Considerations

Anion exchange units lower the water pH, which makes the treated water corrosive. If the treated water is distributed through metal plumbing or used as drinking water for ruminant animals, it may be necessary to follow the anion exchange unit with a neutralizing system. Iron or turbidity may foul anion exchange units, so pretreatment to remove these contaminants may be necessary.

Use caution when disposing of the waste brine produced during regeneration. The brine contains the contaminants removed by the exchange resin, and the contaminants may reenter groundwater or surface water supplies if the brine is deposited on the ground surface, into a leaching pit, or into a septic system.

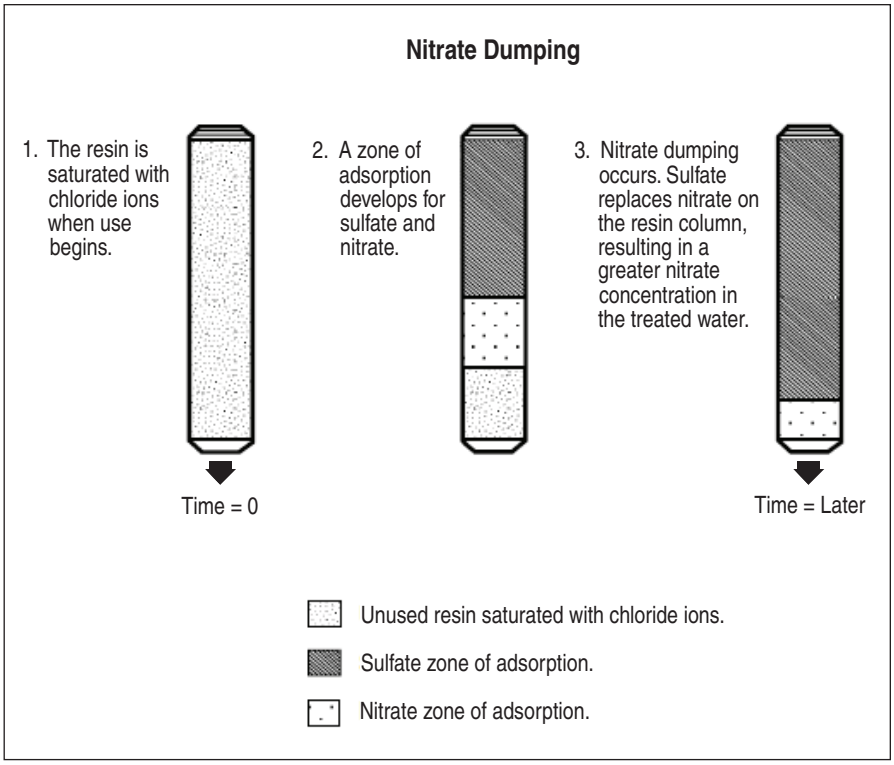

Figure 3.8
Nitrate dumping.

Oxidation

Oxidation processes such as chlorination, greensand filtration, and iodination change the chemical form of some contaminants in water. For example, certain dissolved metals, when oxidized, are changed to particles that can be filtered. Iron and manganese are commonly removed via oxidation. Table 3.5 summarizes methods used to remove iron and manganese. Some oxidizing agents may also kill disease-causing organisms that may be in the water.

Chlorination for Disinfection

Sewage infiltration, improper well construction, or unprotected springs can lead to drinking water contaminated with bacteria, viruses, or other microorganisms that cause disease (patho gens). Chlorination is one way to make microbiologically unsafe water suitable for drinking.

Uses

Chlorine disinfection is a point-of-entry (POE) treatment that kills pathogens, including certain viruses and bacteria. In addition, chlorination can offer residual disinfection throughout the household water distribution system.

The amount of chlorine normally used to disinfect water (0.3 to 0.5 milligram of chlorine per liter of untreated water) does not effectively treat parasitic protozoa such as *Giardia lamblia* or *Cryptosporidium parvum*. *Giardia lamblia* require exposure for fifteen minutes to 1.5 milligrams per liter chlorine at 77 degrees Fahrenheit. *Cryptosporidium parvum* require exposure to 80 milligrams per liter chlorine for two hours at 77 degrees Fahrenheit. In both cases, 70 percent to full-strength chlorine bleach must be used. Because such a long contact time and high chlorine concentration are necessary, chlorination is impractical for protozoa removal. Consult the water treatment key, table 1.3 on page 8, for more suitable removal methods.

Principles

The effectiveness of chlorination depends on various factors including water temperature, water pH, general water quality, and contact time. Chlorination is more effective at a high temperature and a low pH. Turbidity decreases the effectiveness of chlorination, as microorganisms may "hide" behind particles and avoid disinfection.

The contact time is the time available to complete the reaction between the chlorine and untreated water. A longer contact time results in more effective disinfection. The required contact time varies with the chlorine concentration, the types of microorganisms present, and general water quality parameters

Table 3.5
Treatment of iron and manganese

Symptom	Cause	Treatment
Water clear when drawn but red-brown or black particles appear as water stands; red-brown or black stains on fixtures or laundry	Dissolved iron or manganese	• Water softener (see page 41) (<5 milligrams/liter iron) • Manganese greensand (see "Oxidizing filters," page 54) (<15 milligrams/liter iron + manganese) • Chemical oxidation (potassium permanganate, see page 53, or chlorine, see page 52) (>10 milligrams/liter iron) • Phosphates (see page 57; not allowed in some states) (<3 milligrams/liter iron)
Water contains red-brown particles when drawn; particles settle out as water stands	Iron particles from corrosion of pipes and equipment	• Raise pH with neutralizing filter (see page 37)
Water contains red-brown or black particles when drawn; particles settle out as water stands	Oxidized iron/manganese due to exposure of water to air prior to tap	• Particle filter (see mechanical filtration, page 9) (if quantity of oxidized material is high, use larger filter than in-line—for example, media filter)
Red-brown or black slime appears in toilet tanks or clogs faucets	Iron or manganese bacteria	• Kill bacteria masses by shock treatment with chlorine (see page 49) or use potassium permanganate (see page 53), then filter (see mechanical filtration, page 9); bacteria may originate in well, so may require continuous feed of chlorine or potassium permanganate, then filter
Reddish or black color that remains longer than twenty-four hours	Colloidal iron/manganese; organically complexed iron/manganese	• Chemical oxidation with chlorine (see page 52) or potassium permanganate (see page 53); follow with filtration (see page 9)

Source: Linda Wagenet and Ann Lemley, "Iron and Manganese in Household Water," *Water Treatment Notes,* Fact Sheet 6, Cornell Cooperative Extension (1989).

such as pH and temperature. As the chlorine concentration increases, the required contact time decreases.

To ensure a proper contact time, install a holding tank. Table 3.6 lists contact times provided by a 50-gallon, unbaffled holding tank at various water flow rates. Pressure tanks, while often thought to be sufficient, are usually too small to provide a reliable contact time.

A better although more expensive way to provide the necessary contact time is to run the chlorinated water through a coil of pipe. Whereas a pressurized retention tank has an efficiency of approximately 28 percent (due to the possibility of short-circuiting), coiled pipe can achieve an efficiency of 75 to 80 percent. Table 3.6 lists available contact times from 1,000 feet of $1\frac{1}{4}$-inch pipe.

The quality of the untreated water affects the chlorine demand. Chlorine readily combines with other components dissolved in water—including iron, manganese, and hydrogen sulfide; microorganisms; plant material; tastes; odors; ammonia; and organic color such as that from decaying peat moss. These components "use up" chlorine and constitute the chlorine demand of the treatment system. It is important to add sufficient chlorine to meet the chlorine demand and still provide residual disinfection.

The chlorine that does not combine with other components in the water is the free chlorine residual. An ideal disinfection system provides a chlorine residual concentration of 0.3 to 0.5 milligram per liter. The residual should be measured frequently. Simple, inexp ensive test kits, most commonly the DPD colorimetric test kit (so called because diethyl phenylene diamine produces the color reaction), are available.

The residual must be maintained for several minutes. The time varies with chlorine concentration and overall water quality. Tables 3.7 and 3.8 list the necessary contact times for disinfection based on the free chlorine residual, water temperature, and pH.

Chlorine is available in two formulations: as a dry powder or pellet (calcium hypochlorite) or as a liquid (sodium hypochlorite). Both are described in more detail in table 3.9. Chlorine gas, used by public water systems, is too dangerous and expensive for home use.

Chlorine solutions from powders should be prepared frequently since the strength of the solution decreases gradually after mixing. To avoid hardness deposits on equipment, manufacturers recommend using softened or distilled water when mixing chlorine solutions.

Table 3.6

Contact time from an unbaffled 50-gallon holding tank and 1,000 feet of $1\frac{1}{4}$-inch pipe

Water flow rate (gallons/minute)	Contact time from 50-gallon tank (minutes)	Contact time from 1,000 feet of pipe (minutes)
5	7.0	9.2
7	5.0	6.6
10	3.5	4.6

Source: Reprinted from Karen Mancl, "Bacteria in Drinking Water," The Ohio State University, Cooperative Extension Service (1988).

Table 3.7

Contact time for disinfection (water temperature 50˚ F)

Free chlorine residual (milligrams/liter)	Necessary holding time (minutes)		
	pH less than 7	pH between 7 and 8	pH greater than 8
0.5	16	30	40
1.0	8	15	20
1.5	5	10	13
3.0	3	5	7
5.0	1.5	3	4

Source: Reprinted from Karen Mancl, "Bacteria in Drinking Water," The Ohio State University, Cooperative Extension Service (1988).

Table 3.8

Contact time for disinfection (water temperature 32 to 40˚ F)

Free chlorine residual (milligrams/liter)	Necessary holding time (minutes)		
	pH less than 7	pH between 7 and 8	pH greater than 8
0.5	24	40	60
1.0	12	20	30
1.5	8	13	20
3.0	4	7	10
5.0	2.5	4	6

Source: Reprinted from Karen Mancl, "Bacteria in Drinking Water," The Ohio State University, Cooperative Extension Service (1988).

Types

The different types of chlorine disinfection are batch disinfection, simple chlorination, superchlorination followed by dechlorination, shock chlorination, and emergency chlorination. They vary in the amount of chlorine used.

Batch disinfection treats water in batches when the chlorine demand fluctuates. It is especially useful for cisterns, holding tanks, or during emergencies or other special situations. Three tanks, each capable of holding a two to three days' water supply, are alternately filled. The water is treated and used as needed.

Simple chlorination maintains a low level (0.3 to 0.5 milligram per liter) of free chlorine residual for the necessary contact time (see tables 3.7 and 3.8). The residual should be measured at the faucet farthest from the chlorine source.

When the necessary contact time is unattainable, superchlorination followed by dechlorination (chlorine removal) is an option. Superchlorination produces a free chlorine residual of 3.0 to 5.0 milligrams per liter—ten times higher than the residual from simple chlorination. At this concentration, the necessary contact time is reduced to less than five minutes for water at pH 7. Superchlorinated water has a strong chlorine smell and taste that is removable with an activated carbon postfilter (see page 26). If the water contains dissolved iron, manganese, or sulfur, it may be necessary to install a cartridge sediment filter before the activated carbon unit to prevent clogging. See page 10 for a discussion on cartridge filtration.

Shock chlorination, outlined at right, is recommended when a well is new, newly repaired, or temporarily contaminated. This treatment uses very large amounts of chlorine. Unlike superchlorination, shock chlorination is a single event. Dechlorination is not required, as the chlorine is depleted as water flows through the system. If bacteriological problems persist after

Table 3.9
Comparison of liquid and dry chlorine

Liquid chlorine	Dry chlorine
Household bleach most common form	Powder or pellet dissolved in water
Available chlorine: 5.25% (domestic laundry bleach) 18% (commercial laundry bleach)	Available chlorine: 25 to 75% before dilution, 4% after dilution
Slightly more stable than solutions from dry chlorine	Dry powder stable when stored properly; solution maintains strength for one week
Must be protected from sun, air, and heat	Must be protected from sun and heat
	Dry powder fire hazard near flammable materials
	May produce heavy sediment that may clog equipment

Shock Chlorination

- Shock chlorinate after constructing a well, when modifications are made to a well, or when a coliform test is positive.
- Use household bleach containing 5.25 percent available chlorine—the kind sold in supermarkets. The label should indicate that shock chlorination is an approved use.
- Mix 1 quart of bleach with 5 gallons of water; pour into well while pumping. Repeat this procedure. Then:
  - Circulate the solution until a strong chlorine odor is observed at all taps.
  - Continue circulating for one hour.
  - Close all taps and stop the pump.
- Mix an additional 2 quarts of bleach with 10 gallons of water; pour into well without pumping.
  - Allow well to stand at least eight hours (preferably twelve to twenty-four hours).
  - Pump water to waste, away from grass and shrubbery, until chlorine odor dissipates. Chlorine may persist seven to ten days.
- After complete chlorine removal (one to two weeks after flushing), test water for biological contamination.
- Repeat testing in two to three months.

one or two episodes of shock chlorination, install a continuous disinfection system or consider a new water source.

For emergency chlorination or when camping, disinfect small quantities of water by adding a few drops of chlorine. The amount needed varies with the available chlorine. Use table 3.10 as a guide. After adding the proper amount, mix the water thoroughly and let it stand for thirty minutes.

Capacity

The effectiveness of chlorination depends on the amount of chlorine used. The amount is controlled by adjusting the equipment described below or by changing the amount of chlorine added for batch disinfection.

Equipment Options

Various kinds of injection devices and pumps are used to chlorinate a private water supply. The injection device should operate only when the water pump is functioning, and the water pump should shut off if the chlorinator fails or if the chlorine supply runs out. When deciding on a location for chlorination equipment, ensure that the location meets the following criteria:

- Any necessary electric sources are conveniently located.
- Adequate ventilation is provided to exhaust chemical fumes and cool any motors.
- The area is relatively free of dust and dirt, which can collect on movable parts and lead to malfunction.
- The area is protected from excessive sunlight or freezing.
- The area has easy accessibility for maintenance and refilling.
- If using a chemical tank, the tank is located as close as possible to the feeder.

A brief description of common chlorination devices follows.

The most common type of chlorine injection is chemical feed with a positive displacement pump. The pump is activated by water flow. The pump cycle for a positive displacement pump is shown in figure 3.9. The pump motor withdraws a piston to pull back a diaphragm that is part of the pump mechanism. This creates a vacuum in the pump chamber that opens a suction valve and draws in the chlorine. The motor then drives the piston to push on the diaphragm, forcing the chlorine out of the chamber and into the water line.

The amount of chlorine added may be constant or may vary with the flow rate. Water treatment specialists recommend this type of chlorinator when the water distribution system has low or fluctuating water flow rates.

Two types of suction devices can be used to inject chlorine into a water supply. The first type consists of a single line that runs from the chlorine

Table 3.10
Guidelines for emergency chlorination

Available chlorine in bleach (%)	Number of drops of chlorine bleach per gallon of untreated water	
	Clean water	Turbid water
4 to 6	8	16
7 to 8	4	8

Source: Adapted from Karen Mancl, "Bacteria in Drinking Water," The Ohio State University, Cooperative Extension Service (1988).

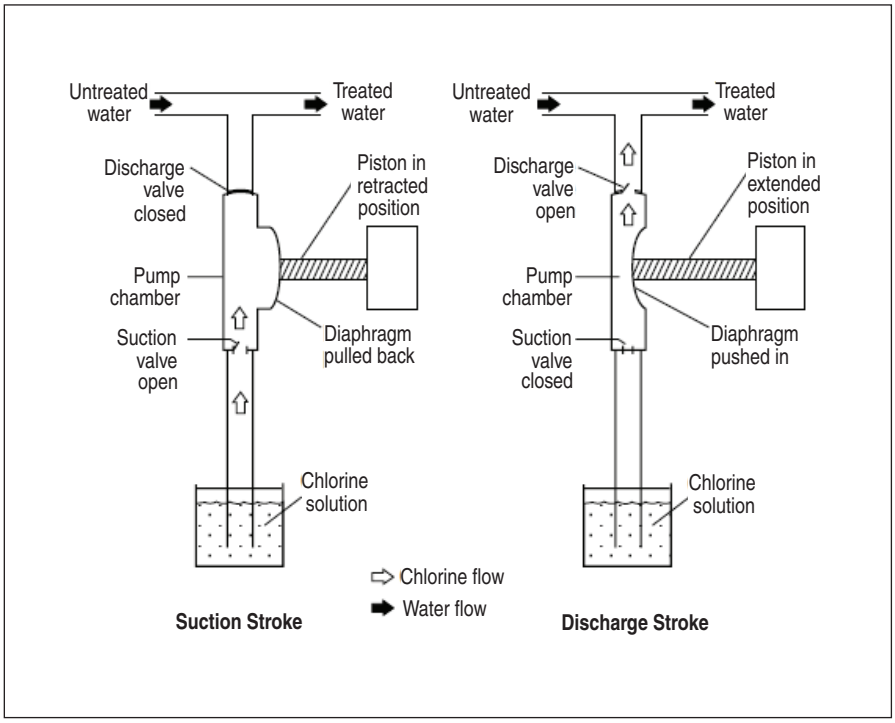

Figure 3.9
Positive displacement pump.

solution container through the chlorinator unit to the suction side of the pump. The suction created by the water pump pulls the chlorine solution from the container.

The second type of suction device introduces the chlorine solution directly into the well. This type also consists of a single line, but the line terminates in the well below the water surface instead of on the influent side of the water pump. Operation of the water pump opens a valve in the chlorinator and pulls the chlorine solution into the well.

In both of these devices, a control valve regulates the solution flow rate, and the chlorinator operates only when the pump is operating. The pump circuit should be connected to a liquid-level sensor so that the water supply pump stops when the chlorine solution is exhausted.

An aspirator, illustrated in figure 3.10, operates on a simple hydraulic principle: The vacuum created when water flows through a venturi tube draws the chlorine solution from a container into the chlorinator unit, where it is mixed with water passing through the unit. The solution is then injected into the water system.

In most cases, the water inlet line to the chlorinator is connected to receive water from the discharge side of the water pump, with the chlorine solution being injected back into the suction side of the same pump. The chlorinator operates only when the pump is operating. A control valve regulates the solution flow rate, although pressure variations may cause changes in the feed rate.

Pellet droppers and erosion chlorinators are the two types of solid feed units that deliver chlorine. A pellet dropper, illustrated in figure 3.11, sits over the top of the well and drops solid chlorine tablets directly into the water. Pellet drop rates for various

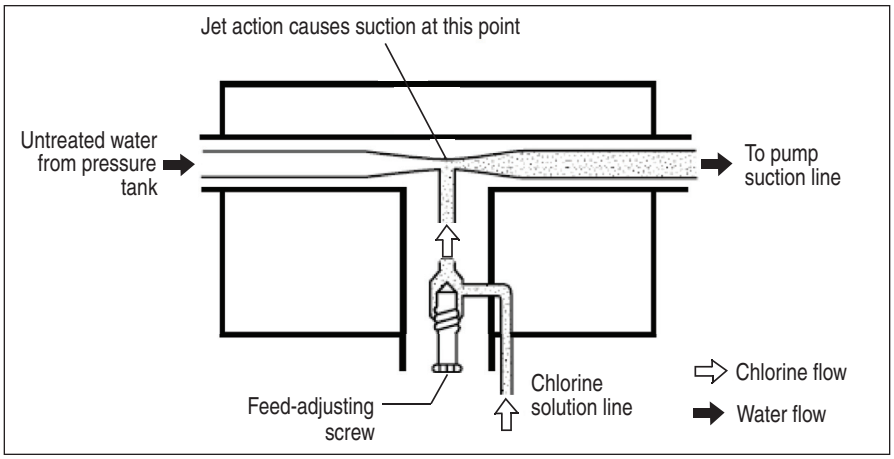

Figure 3.10
Aspirator chlorinator.

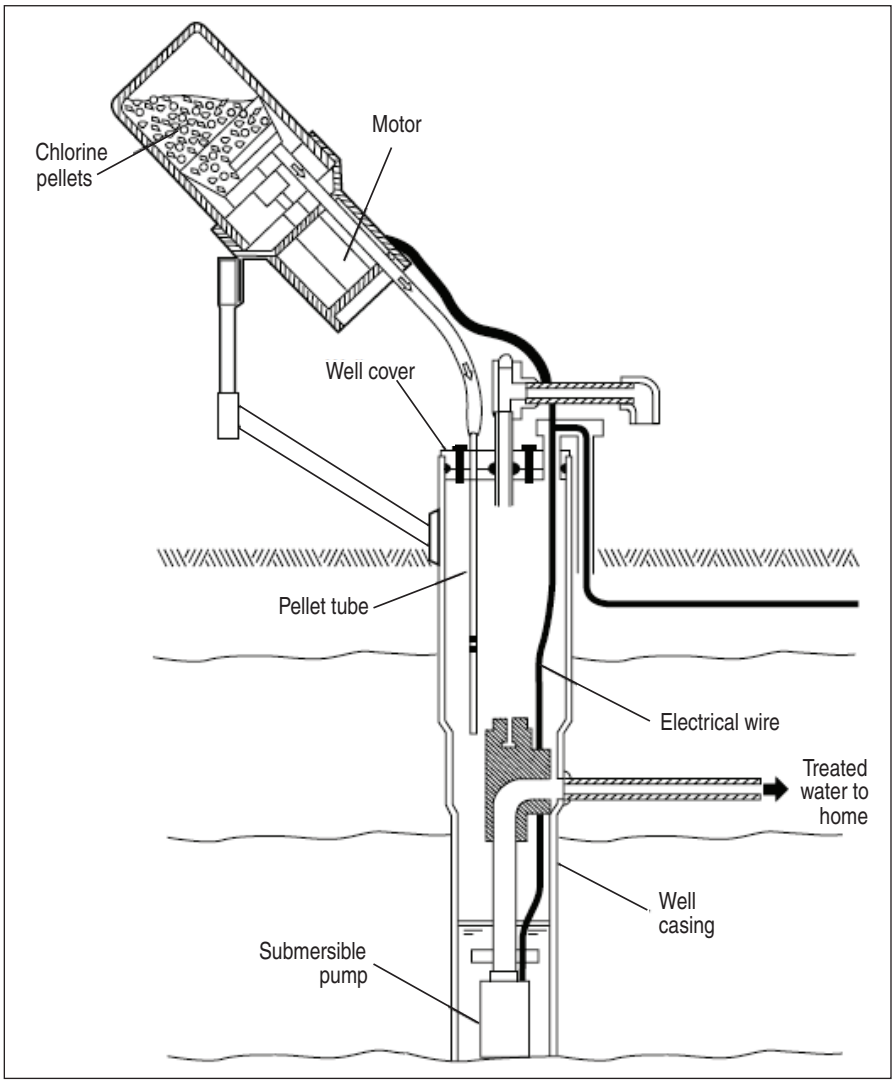

Figure 3.11
Chlorine pellet dropper.

volumes of water are given in table 3.11. Pellet droppers must be properly secured above the well so that the mount is able to withstand weather, bumps, and servicing. In addition, the well must be vented properly to prevent moist air from entering the pellet housing, which results in pellets cementing together. Vents may be included with the chlorinator but sometimes must be bought separately.

In the erosion chlorinator, water passes over chlorine tablets, dissolving them to supply a chlorine solution. A water meter controls the amount of water passing over the tablets. This system does not require electricity, but maintaining a consistent concentration of chlorine is difficult.

Maintenance

Maintaining a chlorination system may involve periodically checking for loose, worn, missing, or broken parts; lubricating the entire system semiannually; cleaning all surfaces showing corrosion; refilling chlorine supplies; and cleaning any clogged orifices. Be sure to unplug any power cords before maintenance.

Special Considerations

Trihalomethanes (THMs) are chemicals that form when organic material from the breakdown of plants and leaves combines with chlorine. They are most common in surface water. Groundwater rarely contains high levels of these organic materials.

Table 3.11
Chlorine pellet drop rate chart

Estimated chlorine usage		
Gallons of water treated per pound of pellets	**Gallons of water treated per pellet**	**Chlorine dosage rate (milligrams/liter)**
28,000	49	3
14,000	25	6
9,333	16	9
7,000	12	12
5,600	10	15
4,666	8	18
4,000	7	21
3,500	6	24
3,100	5.4	27
2,860	5	30
2,333	4	36
1,766	3	48
1,566	2.7	54
1,400	2.5	60
1,133	2	75
932	1.6	90
700	1.2	120
566	1	150
366	0.7	225

Source: Reprinted with permission from *Water Technology* magazine.

THMs are linked to increases in bladder and rectal cancers. The potential for human exposure to THMs from chlorinated drinking water varies with season, contact time between the chlorine and water, water temperature, pH, water chemistry, water consumption, and the disinfection method used.

Although consuming THMs in chlorinated drinking water presents some risk, the health hazards of consuming microbiologically unsafe water are much greater. THMs can be removed with certain activated carbon devices.

Both solid and liquid formulations of chlorine can irritate the skin and are poisonous in concentrated form. They must be handled and stored carefully. Chlorine tablets should be stored in a dry location. Both liquid and solid formulations should be stored in their original labeled containers, away from children and animals.

Light triggers photochemical reactions that reduce the potency of chlorine solutions, so store solutions in opaque containers or in a dark place.

Chlorination for Iron, Manganese, and Hydrogen Sulfide Removal

Iron and manganese do not affect health, but they do make water bitter, stain laundry and fixtures, and discolor water. The U.S. Environmental Protection Agency (EPA) has given a Secondary Drinking Water Standard of 0.3 milligram per liter for iron and 0.05 milligram per liter for manganese. Hydrogen sulfide is a nuisance contaminant that gives water a "rotten egg" odor.

Uses

Chlorination devices are point-of-entry (POE) devices that oxidize dissolved iron to red particles and dissolved manganese to black particles. Hydrogen sulfide, present in groundwater as a gas with a "rotten egg" odor,

oxidizes to yellow sulfur particles upon chlorination. Once oxidized, these contaminants can be filtered by one of several mechanical filtration devices (see the water treatment key, page 8, for more information).

Under certain conditions, iron and manganese combine with organic materials present in the water. Chlorine also oxidizes these organically complexed iron and manganese compounds to solids that are removable via filtration. However, it takes more chlorine and a greater contact time to remove these compounds than to remove inorganic iron and manganese.

Chlorine kills iron, manganese, and sulfur bacteria, which are not hazardous but cause a red-brown or black slime that appears in toilet tanks and clogs faucets. The gelatinous mass resulting from chlorination must be removed via filtration. Shock chlorinating the water source before installing iron, manganese, or hydrogen sulfide filtration equipment also kills the bacteria. (Shock chlorination is described in more detail on page 49.)

Principles

As it percolates through rock, groundwater dissolves iron and manganese that occur naturally in the rock. In dissolved form, these minerals are colorless. Chlorine oxidizes iron and manganese into red-brown or black particles and hydrogen sulfide into yellow particles so that removal by filtration is possible.

A pH between 6 and 8 is best when chlorinating for iron or hydrogen sulfide removal. If the pH is too low in iron-bearing waters, add a caustic material such as soda ash along with the chlorine to raise the pH above 6. Each milligram per liter iron requires 0.3 milligram per liter free chlorine for oxidation. Manganese removal is most effective when the pH is greater than 9.5, and each milligram per liter manganese requires 1.3 milligrams per liter free chlorine for effective oxidation. Higher dosages of chlorine are needed to effectively oxidize hydrogen sulfide: Each milligram per liter hydrogen sulfide requires 9.0 milligrams per liter free chlorine.

A certain amount of contact time between the contaminant and the chlorine is required. Contact usually occurs in the water system's pressure tank, although water might not remain in the tank long enough for complete oxidation. A rule of thumb is to provide a tank that has ten times the capacity of the chemical feed pump. Multiply the capacity of the chemical feed pump (in gallons per minute) by ten to determine the pressure tank size in gallons.

An alternative to using a tank to achieve an adequate contact time is superchlorination, or adding much more chlorine than is necessary. This procedure, described in more detail on page 49, results in more efficient oxidation but the excess chlorine must be removed with an activated carbon filter.

Chlorine is available in two forms: as a dry powder or pellet (calcium hypochlorite) or as a liquid (sodium hypochlorite). For more information on the types of chlorine, see table 3.9 on page 49.

Capacity

The effectiveness of chlorination depends on the amount of chlorine added to the water. The amount is controlled by adjusting the equipment used to add the chlorine. For more information on chlorination equipment, see the section entitled "Equipment Options" on page 50 of the "Chlorination for Disinfection" section.

Maintenance

The same type of equipment used in chlorination for disinfection systems can be used in chlorination for iron, manganese, and hydrogen sulfide removal systems. For more information on the maintenance requirements of such equipment, see the "Maintenance" section on page 52 of the "Chlorination for Disinfection" discussion.

Filtering devices, necessary after this type of chlorination to remove the resulting particles, require regular backwashing, media replacement, or both.

Special Considerations

Chlorination to oxidize iron, manganese, and hydrogen sulfide often results in residual chlorine in the treated water. If a chlorine residual is unnecessary for disinfection or control of iron bacteria, activated carbon can remove the residual and any chlorine taste. Activated carbon can also remove oxidized iron, manganese, or hydrogen sulfide particles, but it is better to filter the particles with a mechanical filter because particles can quickly clog the carbon cartridge. See page 26 for more information on activated carbon.

Trihalomethanes (THMs) are chemicals that form when naturally occurring organic materials combine with free chlorine. THMs are linked to increases in some cancers. For more information on their occurrence in chlorinated water, see the "Special Considerations" section on page 52.

Oxidation with Potassium Permanganate

Potassium permanganate oxidizes dissolved iron, manganese, and hydrogen sulfide into solid particles that can be filtered. The particles formed with potassium permanganate treatment are larger and therefore easier to filter than those formed when chlorine is the oxidizing agent.

Uses

Potassium permanganate is a point-of-entry (POE) treatment method that oxidizes dissolved iron, manganese, and

hydrogen sulfide. It can also be used to control iron bacteria growth in wells.

Principles

Potassium permanganate is available as a dry, purplish solid. For treatment of dissolved iron, manganese, and hydrogen sulfide, a device injects a solution of potassium permanganate into the water between the water pump and the holding tank. The holding tank should be able to hold a fifteen-minute supply of water at peak demand. For example, if the pump rate is 10 gallons per minute, use a 150-gallon tank. The water pH should be between 6 and 9. Use sufficient permanganate to create a slight pink tint in the water at the point of injection.

Potassium permanganate oxidizes iron, manganese, and hydrogen sulfide into particles. The particles are then filtered with either manganese-coated aluminum silicate above manganese-treated greensand or an 8-inch layer of anthracite above manganese-treated greensand. If an insufficient amount of iron, manganese, or hydrogen sulfide is oxidized prior to filtration, the manganese coating on the filter media acts as a backup oxidant to treat any remaining contaminant. If too much potassium permanganate is fed into the water prior to filtration, the excess potassium permanganate serves as a regenerant for the filter media. The water should be colorless (have no pink tint) when it leaves the filter.

When treating water to remove iron bacteria, a solution of potassium permanganate is fed into the well. A concentration of 1,000 to 2,000 milligrams per liter has been found to be very effective. After the solution is in the well, continuous agitation will help loosen and disintegrate sediment and organic material produced by the bacteria, thus enhancing treatment effectiveness. Agitation can be accomplished by turning the well on and off, which brings water up through the well casing and then lets it fall back into the well.

Maintenance

Potassium permanganate supplies must be periodically refilled as part of the maintenance routine. If using potassium permanganate in a well, periodic treatment to dissolve iron deposits and mineral scale may also be necessary. Such treatment requires the use of strong acids, so consult a water treatment specialist for guidance. Potassium permanganate injection devices and pumps are similar to those used in chlorination systems. For more information about such devices and their maintenance requirements, see the sections entitled "Equipment Options" and "Maintenance" in the "Chlorination for Disinfection" discussion, which begins on page 47.

Special Considerations

Using potassium permanganate requires careful calibration, maintenance, and monitoring. Potassium permanganate is sensitive to temperature extremes and performs best between 50 and 72 degrees Fahrenheit. Well water is approximately 55 degrees Fahrenheit.

Potassium permanganate is poisonous and irritates skin, so handle it carefully and ensure that there is no excess potassium permanganate in the treated water. The chemical gives water a slight pink tint. Water should be colorless after treatment. The concentrated chemical must be stored in its original container, away from children and animals. Protect storage containers from physical damage.

Oxidizing Filters

Oxidizing filters oxidize and filter iron, manganese, and hydrogen sulfide in one unit. The filter contains one of a variety of media, the most common being manganese-treated greensand. Other media used are manufactured zeolite, which is a crystalline formulation of aluminates and silicates coated with manganese oxide; plastic resin beads; Birm, which is a light silicon dioxide with a manganese dioxide coating; or Filox, another manufactured resin.

Uses

An oxidizing filter is an in-line, point-of-entry (POE) device that precipitates and filters dissolved iron, manganese, and hydrogen sulfide.

Principles

In many oxidizing filters, the media granules are prepared by washing them with a chemical—commonly potassium permanganate. This forms a black manganese oxide coating on the medium. The coating reacts with the iron, manganese, and hydrogen sulfide to form solid particles that are then trapped in the filter. Figure 3.12 illustrates a manganese greensand filter.

Birm does not require a potassium permanganate wash. Instead, Birm adsorbs oxygen and iron present in the untreated water, which puts the two elements in close contact so that oxidation can occur. Birm is variably effective in oxidizing manganese. Although it can also oxidize hydrogen sulfide, the sulfur particles formed foul the Birm bed. Birm is not consumed in the oxidation process; therefore, it does not need to be regenerated with a chemical such as potassium permanganate. It does require periodic backwashing, however, to remove the accumulated particles.

Untreated water must meet specific requirements for Birm to be effective. For example, the dissolved oxygen content should be at least 15 percent of the iron content; the pH should be at least 6.8 for iron treatment and above 7.5 for manganese treatment; and the water should contain no hydrogen sulfide. Table 3.12 gives various other statistics for Birm, Filox, and manganese greensand.

Capacity

Most oxidizing filters remove up to 10 milligrams per liter iron or manganese every several weeks. Hydrogen sulfide, however, may exhaust a filter very quickly and necessitate regeneration every few days. Therefore, use oxidizing filters only for small amounts of hydrogen sulfide.

Most oxidizing filters remove 75 to 90 percent of the iron or manganese in water. It may be necessary to follow the oxidizing filter with a water softener if the iron or manganese concentrations are not sufficiently reduced.

Maintenance

Particles can clog the filter within a few days to a few weeks, so regular backwashing is necessary to assure

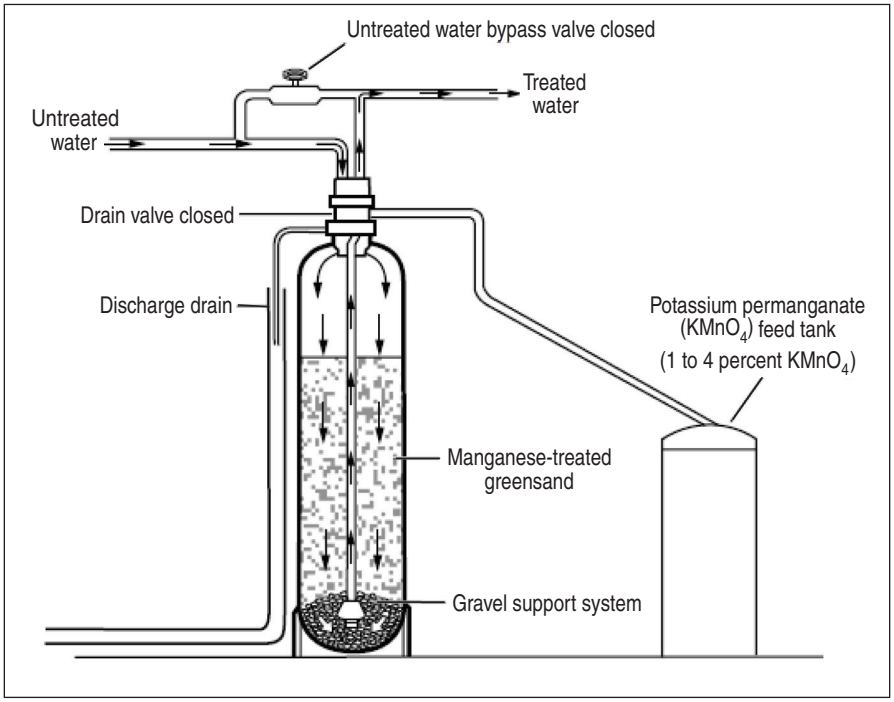

Figure 3.12
Manganese greensand filter.

Table 3.12
Specifications for various oxidation media

	Media		
	Birm™	**Filox™**	**Manganese greensand**
Service flow rate (gallons/minute/square foot)	5	15	3 to 5
Backwash flow rate (gallons/minute/square foot)	10	15 to 18	12
pH range	6.8+	3 to 12	6.2 to 8.8
Dissolved oxygen content required in untreated water	15 percent of iron content	None	None
Bed depth (inches)	30 to 36	30	30
Bed expansion during regeneration	50 percent	50 percent	50 percent
Regenerant	None	None	Potassium permanganate
Dissolved iron (Fe^{2+}) reduction capacity	25,900 to 32,300 milligrams/cubic foot bed volume	312,000 milligrams/cubic foot bed volume	10,000 milligrams/cubic foot bed volume
Dissolved manganese (Mn^{2+}) reduction capacity	Consult manufacturer	1,040,340 milligrams/cubic foot bed volume	1,040,340 milligrams/cubic foot bed volume
Dissolved hydrogen sulfide (H_2S) reduction capacity	None	610,000 milligrams/cubic foot bed volume	2,000 to 3,000 milligrams/cubic foot bed volume

Source: Adapted with permission from *Water Technology* magazine.

that the filter is working properly. With certain oxidizing filters, the manganese oxide coating is consumed, so regeneration may also be necessary. In many instances, the backwashing or regeneration chemical is potassium permanganate. For homes without the required backwash flow rate, many vendors offer a backwashing or regeneration service. They will supply a fresh filter and take the exhausted filter off-site for regeneration.

It is very important that the filter be kept clean. If the filter is not completely cleaned, a reddish-brown sludge will enter the distribution system. Do not use acid cleaners on zeolite, as the acid degrades the zeolite; use chlorine instead.

Special Considerations

In its concentrated form, potassium permanganate stains and irritates skin and is poisonous. Use caution when handling the chemical and store it in its original, labeled container out of reach of children and animals.

Iodination

Iodine has been used to disinfect water since the early 1900s. Currently, the U.S. Environmental Protection Agency (EPA) approves iodination only for short-term or emergency use due to health effects concerns. Iodination is not recommended for routine use where iodine residual may remain in the treated water.

Uses

Iodination is a disinfecting process that kills bacteria and some viruses. Because it is not recommended for long-term use, iodination is used primarily for emergency or temporary disinfection such as during camping trips, while traveling, or when a well is temporarily contaminated. Iodine is not effective in treating water for organic or inorganic chemical contamination, nor is it an effective algaecide.

Principles

In its natural state, iodine is a solid black crystal that is soluble in water. The higher the temperature, the more easily iodine dissolves. Iodine remains effective over a wide range of pH levels and does not lose its effectiveness until the water pH reaches 10. Chlorine, on the other hand, loses effectiveness above pH 8.

Types

Iodine is available in two forms: as a tablet and as a tincture. Iodine tablets were developed during World War II to disinfect small amounts of water for emergency or temporary use. This type of disinfection is popular with campers, the military, and the space program. A tincture of iodine from a household medicine cabinet will also disinfect water. Table 3.13 gives the appropriate doses of tincture of iodine for disinfecting either 1 quart or 1 gallon of water. After adding the proper amount of iodine, mix the water thoroughly and let it stand for thirty minutes.

Iodinated resins, a third type of iodination, have been in use worldwide since the 1970s. Their use in the United States is limited, however, because they are not yet approved by the EPA due to concerns about possible health effects. To win EPA approval, they must remove all residual iodine from the treated water. Consult a water treatment specialist for more information about the current status and availability of this technology.

Iodinated resins are manufactured by attaching iodide ions to an anion exchange resin. Figure 3.13 shows the structure of an iodinated resin bead. The positive charge on the structure attracts microorganisms such as bacteria and viruses, which are killed on contact.

Because the resins release iodine only upon contact with microorganisms, they are referred to as "demand-release" resins. They minimize residual iodine present in the treated water, thus minimizing any possible health effects. (Constant-release resins are also available, but they do not reduce iodine residual and thus do not address the concern about health effects.)

Iodinated resin water treatment is a three-stage process requiring pretreatment and posttreatment. First, sediment filtration removes any particulate matter that might interfere with the disinfection process. Stage two is the iodinated resin disinfection process. Stage three incorporates activated carbon filtration to remove residual iodine from the treated water.

Maintenance

Iodinated resin systems require very little maintenance. The resins have a very large capacity and do not require frequent replacement. Consult manufacturers' recommendations for more information. In addition, they do not require an external source of electricity, cannot be biologically fouled, and can be left for long periods of time.

Table 3.13
Emergency disinfection with iodine

Volume of water	Number of drops of tincture of iodine	
	Clean water	Turbid water
1 quart	5	10
1 gallon	20	40

Source: Adapted from Karen Mancl, "Bacteria in Drinking Water," The Ohio State University, Cooperative Extension Service (1988).

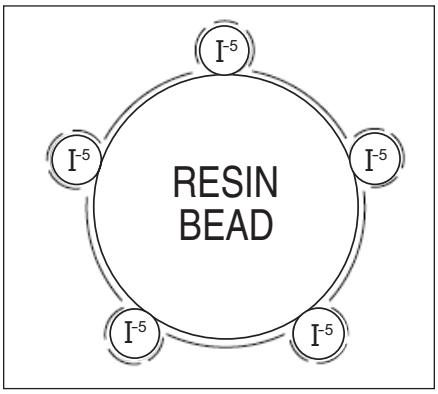

Figure 3.13
Iodinated resin bead.

Special Considerations

In 1982, the EPA issued a policy stating that iodine disinfection is acceptable only for short-term or emergency use. Long-term iodine use is unacceptable because residual iodine may be a problem for people with thyroid conditions. Nevertheless, some states allow the use of iodination; consult local regulations for more information.

All iodine technologies must be registered with the EPA. Currently, the only approved technology is a traveler's pour-through cup that must carry a label stating that it is to be used only for emergencies.

Iodine treatment for dairy drinking water supplies is also a concern. Dairy cattle can drink 15 to 25 gallons of water per day. Iodine residuals in the treated water may carry over into milk.

Phosphates

Phosphates sequester, or "tie up," metals and minerals to prevent problems associated with hardness or dissolved iron. Without treatment, the minerals and metals would oxidize and settle, which results in soap film formation.

Uses

Phosphate treatment is usually point-of-entry (POE). It reduces hard water problems and treats small amounts of dissolved iron in water supplies. Phosphates cannot treat iron particles and are ineffective against iron bacteria.

Principles

Phosphate compounds such as sodium hexametaphosphate sequester iron or hardness minerals instead of removing them. Consequently, a metallic taste may develop in the treated water.

Phosphates can be added to water with a bypass saturator or a chemical feed pump. A bypass saturator is an in-line device that adds dissolved phosphate to the water supply. Untreated water is diverted to the saturator, where it dissolves phosphate crystals. The resulting phosphate solution reenters the water line. One problem with these devices is that the solution concentration will fluctuate with water flow, but bypass saturators are simpler and less expensive to operate than chemical feed pumps.

Capacity

The phosphate dosage is set through trial and error. Use approximately 5 milligrams per liter phosphate for every 1 milligram per liter iron. The total phosphate dosage usually ranges from 2 to 20 milligrams per liter. Phosphates can tie up as much as 3 milligrams per liter dissolved iron.

Maintenance

To maintain a chemical feed pump, periodically inspect the pump and restock the chemicals. For bypass saturators, replenish the solid phosphate. Both devices should be checked periodically for worn, broken, or loose parts and for clogs.

Special Considerations

Phosphates are a common component in detergents or other laundry additives. Some states, hoping to reduce the incidence of algal blooms in lakes, reservoirs, and other surface waters, have banned the sale of phosphate detergents. Consult a state environmental agency or cooperative extension office for more information on any local restrictions. High doses of phosphate in drinking water give water a slippery feel and may cause diarrhea.

Aeration

Until recently the most common way to remove volatile organic chemicals (VOCs) from water was with an activated carbon device. Aeration, however, removes the volatile chemicals without creating a solid waste product such as spent carbon.

Aeration is the general term for introducing air into water to reduce the concentration of a variety of contaminants—most often VOCs. Aeration devices range from a simple, open holding tank that allows dissolved gases to diffuse into the atmosphere to a more complex aeration system that has a column or tower filled with packing material. As water passes through the packing material, the gases are released. This section focuses primarily on the more complex aeration systems.

Uses

Aeration is an in-line, point-of-entry (POE) process that reduces the concentration of VOCs such as chlorinated hydrocarbons (tetrachloroethylene, trichloroethylene, and carbon tetrachloride). Aeration also removes dissolved gases such as hydrogen sulfide, methane, and radon.

Aeration oxidizes dissolved iron, although the resulting iron particles can foul the packing material in some aeration devices. Therefore, remove iron from the water prior to aeration treatment. For a summarization of methods used to remove iron, see table 3.5 on page 47.

Principles

Aeration vaporizes a contaminant by injecting air into the water. A vent releases contaminants into the atmosphere. Water repressurization is usually necessary following treatment. Repressurization involves installing a pump after the treatment device to distribute the water throughout the home.

Types

The three types of aeration devices common in home usage are packed tower aerators (PTA), multistaged diffused bubble aerators, and spray aerators. The PTA system shown in figure 3.14 has a tower that may be as tall as 10 feet and is filled with packing material. This packing material can range from ¼ inch to 3 inches in size and may be pieces of ceramic or plastic. There is no strong evidence indicating that one type of packing material is preferable to another. In general, however, the smaller the individual pieces of a particular type, the greater the removal efficiency but the higher the energy costs for air pumping.

In PTA systems, water falls from the top of the tower by gravity while air is blown from the bottom of the unit in a direction opposite to the water flow. Volatile contaminants are transferred to the air, rise to the top of the tower, and vent to the outside. Carefully monitor water flow in the packed tower aerator to prevent flooding at the top of the column. Manage the flow by choosing an appropriately sized packing material and by controlling the air-to-water ratio.

A diffused bubble aerator, illustrated in figure 3.15, has several chambers and a diffuser through which air blows. The diffuser produces fine bubbles that rise through the water as it flows from chamber to chamber. These bubbles carry the volatile chemicals through a vent system to the outside atmosphere. The more chambers the system has, the greater the air-to-water contact. Some diffused bubble aerators have a high-float switch that triggers an alarm when the chambers are in danger of flooding.

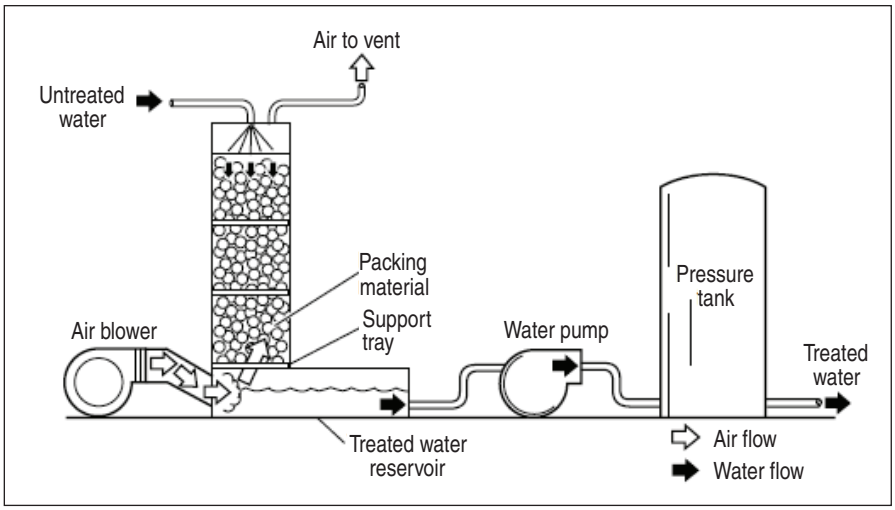

Figure 3.14
Packed tower aerator.

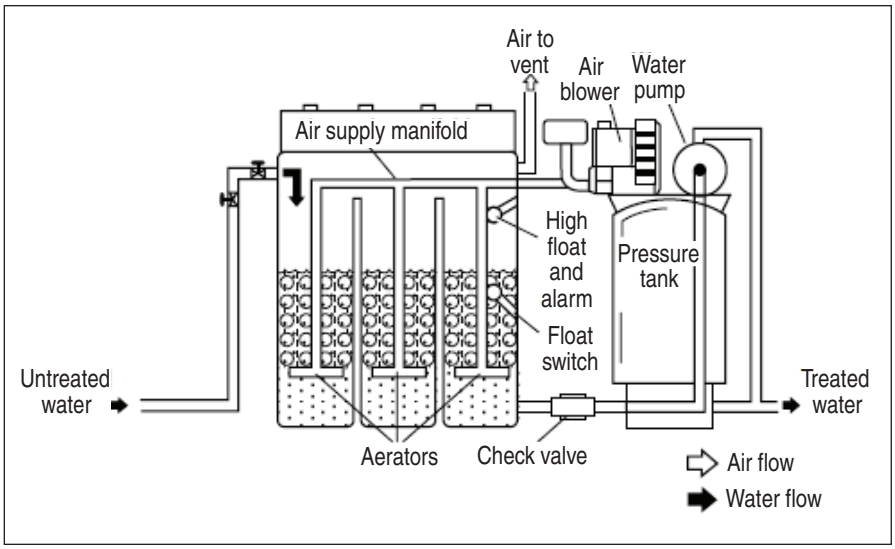

Figure 3.15
Diffused bubble aerator.
Adapted from the American Society of Agricultural Engineers.

The packed tower system is better if a water pump follows the treatment system. The energy requirement for each device is similar. Contaminants emitted from these devices must vent to the outside atmosphere to prevent exposure to hazardous chemicals.

The third type of aeration, spray aeration, removes low levels of volatile contaminants—especially radon. A spray aeration system is illustrated in figure 3.16. Water enters through the top of the unit and emerges through spray heads in a fine mist. Treated water collects in a vented tank below the spray heads. Radon and other volatile contaminants are released and vented to the outside atmosphere.

Maintenance

To ensure efficient operation, maintain the blower for packed tower and diffused bubble aerators by periodi-

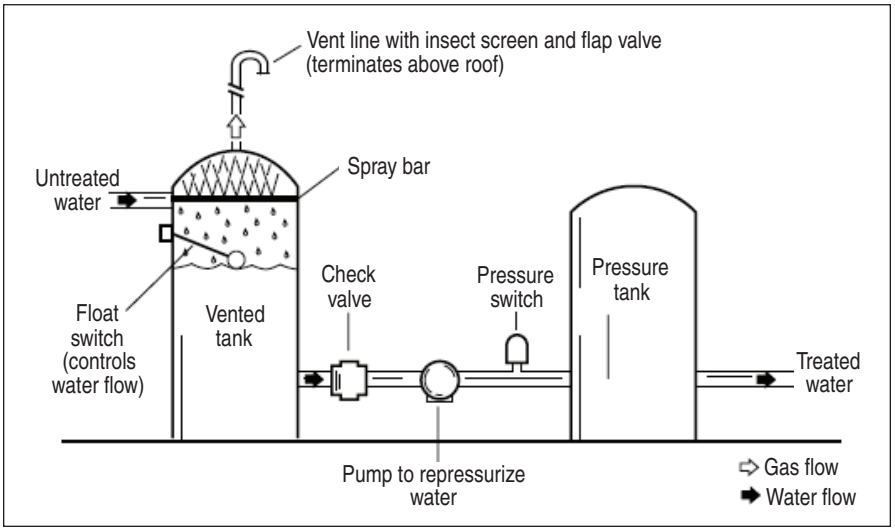

Figure 3.16
Spray aerator.
Reprinted from the *Water Well Journal,* National Well Water Association.

cally lubricating the motor and changing the air filters. Aeration tanks and trays accumulate slimes and precipitates, and these must be removed periodically as well. In addition to aerator maintenance, carbon filters on activated carbon posttreatment devices also need to be changed. Activated carbon posttreatment is sometimes used to further reduce the concentration of organics in the treated water. For more information on activated carbon, see the discussion beginning on page 26.

Special Considerations

Aeration systems remove volatile chemicals from water and release them into the atmosphere. Be sure to consider the height and location of the gas vent for the aerator tower or basin and any contaminants that may exit into the atmosphere.

The best location for an aeration system is away from the residence in an outbuilding. If housing the system in an outbuilding, be sure to consider the added energy costs of pumping the water to this building and back to the household distribution system. Also keep in mind that aeration produces a fairly corrosive water, so all water distribution components should be made of corrosion-resistant materials such as plastic.

Aeration systems are generally more expensive than other water treatment systems. They are most often used in situations where the levels of VOCs are extremely high. If the VOC concentration is below 1 milligram per liter, or if radon levels are below 5,000 picocuries per liter, activated carbon may be a more economical treatment method. If, on the other hand, the VOC concentration exceeds 1 milligram per liter, radon levels are above 5,000 picocuries per liter, or a large quantity of water is to be treated, aeration may be a more viable alternative.

Another consideration is the length of time that treatment is required. If the water source is only temporarily contaminated, aeration may be a more complex system than is necessary; use activated carbon instead. For more information on activated carbon, see the section beginning on page 26.

Some concern exists about the potential for microorganism growth on the packing material in PTA systems. For this reason, many aeration systems employ a disinfection unit such as a chlorination device after the aeration system and just prior to the household water distribution system. For more information on disinfection systems, see the water treatment key, table 1.3, on page 8.

Ozone

Ozone is an unstable form of oxygen gas that was first used to treat drinking water in Europe in 1893. It is a much stronger and faster oxidizer than chlorine and has been used as a disinfectant and oxidant in large-scale water treatment facilities for many years. Only recently has ozone technology been used in homes.

Uses

Ozone water treatment is usually a point-of-entry (POE) system. Ozone kills bacteria, viruses, and other microorganisms; precipitates many metals; oxidizes iron, manganese, and hydrogen sulfide; and removes color, odor, and many tastes.

Some research has shown that ozone is more effective than chlorine or ultraviolet disinfection for treating *Giardia lamblia* or *Cryptosporidium parvum*. However, ozone is not recommended for use against microorganisms in home water treatment systems. Ozone may be recommended as a pretreatment to control biofouling of reverse osmosis membranes and ion exchange resin, as certain membranes and resins are degraded by chlorine.

Principles

Ozone is an odorous, highly unstable gas formed from pure oxygen or ambient air. Home systems usually use ambient air. Because it reverts to oxygen soon after formation, ozone must be generated at the point where it is used.

Ozone is produced in one of two ways: by exposing oxygen-containing gas to ultraviolet (UV) radiation or by passing it through a corona discharge

device, which is a high-energy electrical apparatus. The corona discharge method, illustrated in figure 3.17, uses about the same amount of electricity as a television set.

Most ozone generators are equipped with an air-drying mechanism that dries the incoming air prior to ozonation. Drying the air increases the ozone production rate, increases the ozone concentration, and ensures a nonfluctuating concentration of ozone in the untreated water.

Ozone is combined with untreated water via a venturi-type injector or via pressurized dosing. At the point where the ozone mixes with the water, turbulence and bubbles are created; these ensure that the ozone contacts as much of the untreated water as possible. The greater the water flow rate, the greater the pressure differential and turbulence, and the more effective the treatment. One problem with injectors is that they may reduce water flow to an undesirable level. Reduced water flow can also interfere with backwashing any pre- or posttreatment filters. Another problem is that contaminants can precipitate and clog the narrow orifice of the injector.

In the pressurized dosing method, which is illustrated in figure 3.18, ozone is pumped into a contact chamber. The ozone is usually forced through a diffuser stone or glass-like material that decreases the ozone bubble size and increases the amount of ozone dissolved in the untreated water. The stone is located near the bottom of the chamber. The bubbles produced rise into the untreated water in the contact chamber. A vent at the top of the chamber allows excess gas to escape. This method tends to require less maintenance but is initially more expensive than the venturi injection method.

The effectiveness of ozonation depends in part on the contact time. In general, ozone requires a shorter contact time than chlorine. The contact time required varies with the water treatment situation, but, in general, 5 to 10 minutes is sufficient In comparison, the contact time for simple chlorination can be as high as 30 minutes.

The solubility of ozone in the untreated water also affects treatment. Solubility depends on the water temperature, the water pH, the ozone demand, and the concentration of ozone generated. In general, the lower the water temperature, the more ozone is dissolved in the water. Ozone has been found to be effective over a wide range of pH, but a slightly alkaline pH (above 7) in-

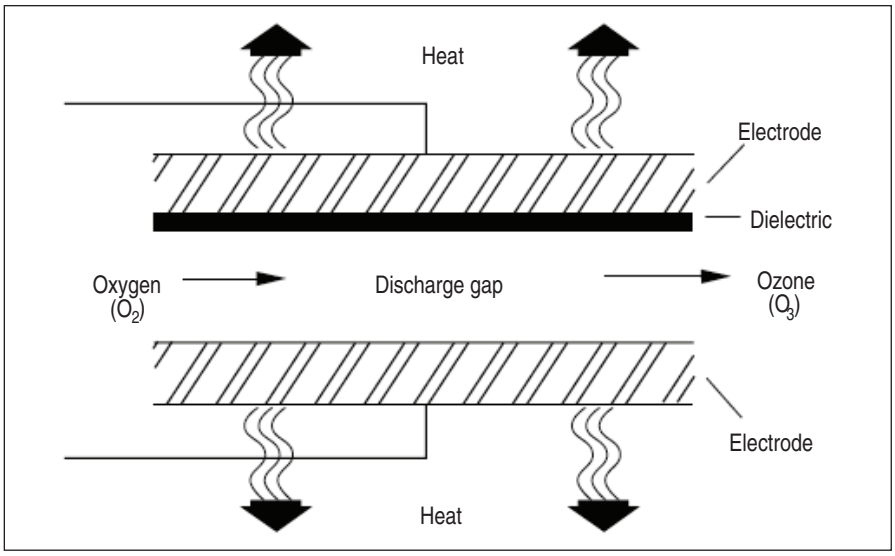

Figure 3.17
Ozone formation.

Adapted with permission from Jay Lehr, Environmental Educational Enterprises, Columbus, Ohio.

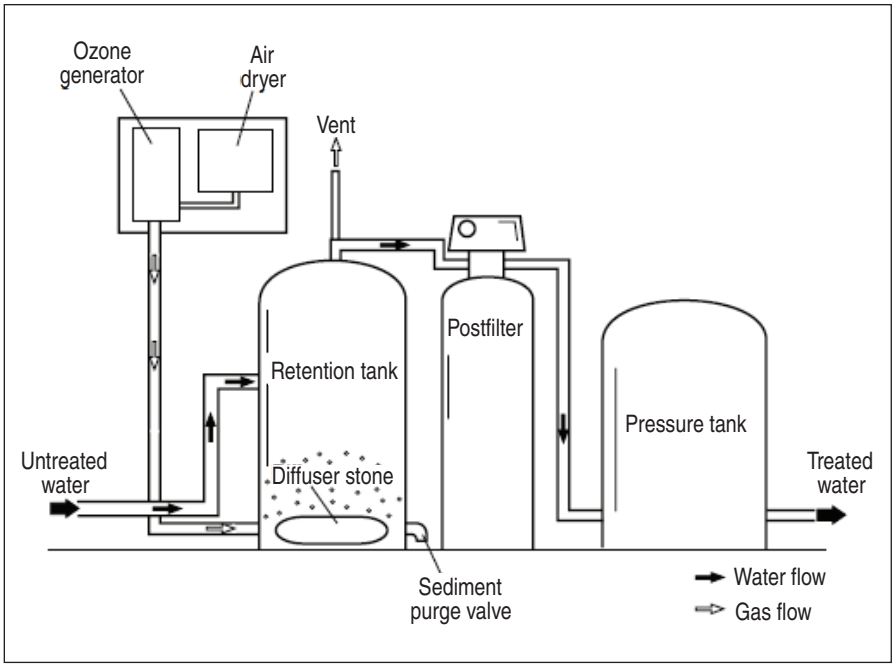

Figure 3.18
Ozonation with pressurized dosing.

Note: The postfilter removes precipitated iron, manganese, and sulfur particles.

creases treatment efficiency. The ozone demand is related to the level of contamination in the water. When substances in the untreated water react with ozone, part of the ozone is "used up," which may leave less ozone available to treat the targeted contaminants.

Only a portion of the air entering an ozone device is converted to ozone. The concentration of ozone generated depends on the method of ozone production. In general, the higher the ozone concentration, the higher the ozone solubility. With UV devices, ozone generally makes up 0.01 to 0.1 percent by weight of the gas leaving the ozone generator. With corona discharge units, the concentration may be anywhere from 1 to 3 percent. UV devices may not be able to attain a high enough concentration to effectively treat some pathogens; water treatment dealers can help determine the concentration needed for any given situation.

Most ozone systems require a storage tank for the treated water. Because ozone is so unstable, it does not produce a reliable residual—a significant drawback. Bacteria and microorganisms can grow in the storage tank and in the water distribution system and recontaminate water after treatment.

Some ozone systems store treated water in the contact chamber to assure that water is continuously treated until used. Other systems are able to maintain a residual of 0.4 milligram per liter for four minutes; it has been determined that such a residual will inactivate 99.99 percent of most viruses. Another option is to supplement ozonation with secondary disinfection. For more information on disinfection processes, see the sections on boiling, distillation, and ultraviolet disinfection in chapter 2 and the section on chlorination for disinfection in this chapter.

Ozone treatment systems frequently have pretreatment and posttreatment devices. Filtration may be required as pretreatment to remove excessive turbidity or suspended solids that may shelter microorganisms from disinfection or foul the ozone device. Filtration may be necessary as posttreatment to remove any oxidized particles. (See the discussion on mechanical filtration, beginning on page 9). Activated carbon is a common posttreatment device for removing partially oxidized organic material. (For more information about activated carbon, see page 26.)

Types

As was stated above, the two types of ozone generators are UV light devices and corona discharge devices. They are compared in table 3.14. UV devices are initially less expensive than corona discharge devices, but they produce lower concentrations of ozone. A dry air supply is not required for UV devices, but drying the air does result in higher ozone concentrations.

Corona discharge devices are more expensive than UV devices but produce more ozone at constant rates and higher concentrations. They require a supply of dry air for operation and need less maintenance than UV devices. Corona discharge tubes can be linked together to produce very high concentrations.

Capacity

The ozone dose required will vary according to water quality, but a typical ozone dose is 1.0 to 2.0 milligrams per liter, which is sufficient to kill most bacteria and control tastes and odors. The rate of ozone production for most UV devices is 0.5 gram per hour for 185-nanometer bulbs and 0.3 gram per hour for 254-nanometer bulbs. Corona discharge devices produce a minimum of 2 grams per hour.

The capacity of the storage tank determines how much water is available for use. The amount of storage required depends on household water use. See table 1.1 on page 5 for help in determining the water use for a specific household.

Table 3.14
Comparison of corona discharge and ultraviolet light ozone generation methods

Parameter	Corona discharge	Ultraviolet light
Maximum ozone production rate	55 grams/kilowatt hour from dry air	1.94 grams/kilowatt hour using 185-nanometer bulbs [a]
Concentration of ozone in output gas	12 to 60 grams per cubic meter	1.8 grams per cubic meter
Energy required to generate 1 kilogram of ozone	6 to 8 kilowatt hours	44 kilowatt hours
Need to dry air	Critical	Desirable but not critical
Constancy of ozone production	Constant	Variable
Capital costs	Relatively high	Relatively low
Operating costs (electrical costs)	Low	High

Source: Adapted with permission from *Water Technology* magazine.

[a] Lower yields are obtained from 254-nanometer ultraviolet light bulbs.

Maintenance

Most home ozone systems do not require extensive maintenance. Some systems use a desiccant, or air-drying material, which needs to be replaced periodically. It is also necessary to periodically clean the water storage tank and check pumps, fans, and valves for damage or wear. If UV radiation generates the ozone, the lamp must be replaced periodically. Any pretreatment or post-treatment devices may require additional maintenance.

In addition, the entire system should be routinely inspected by a water treatment specialist for any ozone leaks. Water treatment equipment dealers have more information on inspection frequency. Some ozone systems have monitoring devices that alert the owner to a malfunction or failure by shutting down the entire system, sounding an alarm, or activating a warning light.

As with any water treatment system, an ozone system should be closely monitored during the first few months after installation to ensure that it is working properly. Periodic water testing thereafter will ensure continued effectiveness.

Special Considerations

Ozone is a stronger disinfectant than chlorine and does not form trihalomethanes (THMs)—byproducts of chlorination that have been linked to increases in certain cancers. Some studies have shown, however, that ozone increases the incidence of certain byproducts of chlorination if chlorination is used as a secondary disinfectant. Ozone treatment itself creates byproducts, but the health effects they may cause are unknown. It is possible that some byproducts of ozonation cause even worse health effects than the contaminants being removed.

Not much is known about the chronic health effects of ozone; there appears to be none among healthy people. In more than eighty years of commercial use, no deaths resulting from ozone exposure have been reported. Short-term health effects can occur from exposure to ozone via leaking ozone systems. Health effects resulting from exposure to 0.1 to 1.0 milligram per liter ozone include headache, dry throat, and irritation and burning of the eyes.

Most people can smell ozone at a concentration of 0.01 milligram per liter (well below the level for general comfort), and breathing traces of ozone for a few minutes is of little health concern. To prevent ozone from entering the home, any residual ozone in the vent gas should be vented outside the home.

In theory, ozonation has no residual such as that provided by chlorination. In point-of-use (POU) water treatment applications, however, some ozone may remain in the treated water because the time between ozone generation and treated water consumption is shorter than in large-scale operations. Again, little information is available about the health effects of ozone-treated water.

Ozone can corrode some pipes and fixtures, so all surfaces coming in contact with ozone should be made of ozone-resistant materials such as stainless steel or Teflon. Also, combustible materials such as gasoline, oil, or grease should not be stored near the ozone system, as ozone may cause fire if it comes in contact with combustibles.

Ozone is one of the most expensive home water treatment technologies, but the water treatment industry is examining ways to make ozone more affordable. Check with water treatment dealers for information on the cost per gallon for treatment.

Final Thoughts

This publication discusses a variety of water treatment methods and drinking water contaminants. Its companion, *Private Drinking Water Supplies: Quality, Testing, and Options for Problem Waters,* NRAES–47, presents a broad view of drinking water quality and the problems facing individuals on private water supplies. Together, they aim to help homeowners make enlightened decisions about how to make their drinking water safe. In this publication, the authors did not thoroughly cover every water treatment system available. Rather, they chose to focus on the most common treatment systems available for the most common water quality problems.

An important theme emphasized throughout this publication is that water treatment is rarely simple. Although there are small treatment devices that simply attach to the kitchen faucet, these devices are suitable only for taste and odor problems—not the complicated health hazards that plague some water sources. A systems approach is crucial to designing effective water treatment schemes. Pretreatment and posttreatment devices are often necessary. Keep in mind that these devices not only improve water quality but also increase cost and maintenance requirements. If the water quality problem involves only tastes, smells, or appearances and not safety, water treatment becomes a matter of personal preference.

State or federal regulations for water treatment systems are a major topic in the water treatment industry today. Lobbyists have labored intensely against such regulations on behalf of the industry. Certain states already make the water treatment industry accountable for claims it makes about equipment.

California and Iowa, for example, require manufacturers to submit performance test data for all water treatment equipment used to remove health-related contaminants; only after the states approve the data can the equipment be sold. Wisconsin approves all water treatment equipment that attaches to pipes (including faucets), whether the equipment removes health-related contaminants or nuisance contaminants. New York requires that water treatment devices be accompanied by a performance data sheet and a label instructing consumers to read the data sheet. Although the law states that the data sheets must be factual, the state does not review the data and does not require that a U.S. Environmental Protection Agency (EPA) or state-certified laboratory test the devices or that a specific test protocol be followed.

The water treatment industry believes that self-regulation is the best regulation. The industry seeks a compromise with state legislatures to assure that consumers are protected from unsubstantiated claims about the effectiveness of water treatment systems or the condition of a particular water supply. Recently, officials in the Water Quality Association (WQA), an industry trade organization, wanted their voluntary ethics guidelines enforced more strictly. Others even suggested publishing the names of companies that continue to violate the guidelines.

Some in the water treatment industry predict that the residential water treatment market in the U.S. will mushroom from $1.64 billion in sales in 1992 to $2.81 billion in 1996—the bulk of the demand being for treatment systems that solve taste and odor problems. Activated carbon, ultraviolet disinfection, and distillation systems are expected to have the largest increases in sales.

Water treatment technology is complex and confusing. The press can make it even more confusing by bombarding consumers with stories about the alleged unhealthy state of both groundwater and surface water. But with a little research, homeowners can make their own decisions. By having their drinking water tested yearly for certain water quality parameters such as coliform, nitrate, pH, and total dissolved solids (TDS), homeowners can monitor the general quality of their water. Further testing can pinpoint specific problems. If a problem does exist, local cooperative extension offices or health departments may be able to assist. *Home Water Treatment* will further help consumers decide on a responsible, reasonable, and effective course of action.

Appendix A

U.S. EPA Primary Drinking Water Standards and Health Advisories

Table A.1
U.S. EPA Primary Drinking Water Standards (as of May 1994)

Inorganic contaminants	Uses and/or sources	Possible chronic health effects [a]	Possible water treatment methods [b]	Maximum Contaminant Level (MCL) [c]
Antimony [d, e]	Used in the manufacture of semiconductors, batteries, glass, ceramics, pesticide products*, ammunition, cable sheathing, and antifriction and flameproofing compounds; used in typecastings for commercial printing; bound to extractable iron and aluminum; found in soils near lead and copper smelters; found in sediment near sewage outfalls and fertilizer facilities; may leach from landfills, sewage sludge, oil-fired incinerator ash, and fertilizers	Decreased longevity, altered blood glucose and serum cholesterol levels	• Distillation • Reverse osmosis	0.006 milligram/ liter
Asbestos	Results from corrosion of asbestos cement pipe in water distribution systems; used in the manufacture of cement products, paper, floor tiles, paint, caulking, textiles, and plastics; occurs in natural deposits	Cancer	• Filtration • Reverse osmosis	7 million fibers (longer than 10 micrometers)/ liter !
Barium [d, e]	Occurs in rocks and soil; found in oil and gas drilling mud; byproduct of coal burning, diesel fuel combustion, and jet fuel combustion; used in automobile paints, pesticide products*, and as x-ray contrast medium	Hypertension	• Cation exchange • Reverse osmosis • Distillation	2.0 milligrams/ liter
Beryllium [d]	Used in metallurgical, aerospace, and nuclear technologies; used in windows for x-ray tubes	Probable human carcinogen, reduction in body weight	• Reverse osmosis • Distillation	0.004 milligram/ liter !

See footnotes on page 73.

Table A.1
U.S. EPA Primary Drinking Water Standards (as of May 1994)—*continued*

Inorganic contaminants	Uses and/or sources	Possible chronic health effects [a]	Possible water treatment methods [b]	Maximum Contaminant Level (MCL) [c]
Cadmium [d, e]	Occurs in rocks, coal, and petroleum; byproduct of zinc production, mining, smelting, refining, and electroplating; found in discarded batteries, paints, plastics, fertilizers, pesticide products*, and sewage sludge; results from corrosion of galvanized pipe; found near landfills and industrial waste sites	Kidney damage	• Cation exchange • Reverse osmosis • pH adjustment to prevent corrosion of water distribution system • Phosphates to prevent corrosion of water distribution system • Distillation	0.005 milligram/ liter
Chromium [d, e] (total)	Occurs in rocks and soil; found near mining sites and in septic systems; used in chrome plating, leather tanning, and in the manufacture of catalysts, pigments and paints, fungicides, and wood preservatives; byproduct of waste incineration; used as a mordant in the textile industry; used for metal finishing and corrosion control	Respiratory disorders, dermatitis, liver and kidney damage, mutagenic effects	• Cation exchange in series with anion exchange (depending on type of chromium) • Reverse osmosis • Distillation	0.1 milligram/ liter
Copper [e, f]	Occurs in rocks and soil; used in coal burning and iron and steel production; found in industrial and sewage treatment plant wastes; results from corrosion of brass and copper pipes; used for algae control in water systems	Anemia, digestive disturbances, liver and kidney damage	• Cation exchange • Reverse osmosis • Distillation • pH adjustment to prevent corrosion of water distribution system	Treatment technique (action level—1.3 milligrams/ liter)
Fluoride [g]	Occurs in rocks and soil; found in industrial waste	Mottling of teeth, bone damage	• Anion exchange • Reverse osmosis • Distillation • Activated alumina	4.0 milligrams/ liter
Lead [d, e, f] (at tap)	Occurs in rocks and soil; results from corrosion of lead pipes and lead-soldered pipe joints; used in the production of gasoline antiknock additives, storage batteries, pigments and ceramics, ammunition, cable coverings, brass and bronze, solder, caulking lead, pipe and sheet lead, type metal, bearing metals, and pesticide products*	Probable human carcinogen; brain and nerve damage, especially in children; kidney damage; digestive disturbances; blood disorders; birth defects	• Cation exchange • Reverse osmosis • pH adjustment to prevent corrosion of water distribution system • Distillation • Some types of activated carbon may be effective • Replace lead plumbing	Treatment technique ! (action level—0.015 milligram/ liter)

See footnotes on page 73.

Table A.1
U.S. EPA Primary Drinking Water Standards (as of May 1994)—*continued*

Inorganic contaminants	Uses and/or sources	Possible chronic health effects [a]	Possible water treatment methods [b]	Maximum Contaminant Level (MCL) [c]
Mercury [d, e]	Occurs in soil and rocks; used in mining, smelting, coal burning, and paper manufacture; found in electrical equipment, fungicides, paints, and industrial wastes	Kidney damage, central nervous system effects	• Activated carbon • Reverse osmosis • Cation and anion exchange in series • Distillation	0.002 milligram/ liter
Nickel [d]	Used in the manufacture of stainless steel and other alloys; used in electroplating; occurs in rocks and soils; can corrode from some plumbing	Reduced body weight or body weight gain	• Cation exchange • Reverse osmosis	0.1 milligram/ liter
Nitrate [d] (as N)	Occurs in soils and mineral deposits; found in fertilizers, sewage, animal wastes, and explosives; used as heat-transfer fluid and heat-storage medium for solar heating applications; used in glass making and meat curing	Methemoglobinemia (blue baby syndrome) in infants	• Anion exchange • Reverse osmosis • Distillation	10.0 milligrams/ liter
Nitrite [d] (as N)	Occurs in soils and mineral deposits; found in fertilizers, sewage, and animal wastes; used in meat curing	Methemoglobinemia (blue baby syndrome) in infants	• Anion exchange • Reverse osmosis • Distillation	1.0 milligram/ liter
Nitrate + nitrite [d] (both as N)	Occurs in soils and mineral deposits; found in fertilizers, sewage, and animal wastes; used in meat curing		• Anion exchange • Reverse osmosis • Distillation	10.0 milligrams/ liter
Selenium	Occurs in soil and shales; used in coal burning, mining, smelting, and the manufacture of glass, paints, and drugs; found in fungicides and feed additives	Skin discoloration, psychological disorders	• Distillation • Reverse osmosis • Activated alumina	0.05 milligram/ liter
Thallium [d]	Used in the manufacture of crystals, jewelry, optics, fiberglass, pigments, corrosion-resistant alloys, catalysts, thermometers, photoelectric cells, and electronic equipment; found in flue dust of copper, zinc, and lead smelters; byproduct of cadmium and sulfuric acid production; used in iron and steel production, the cement industries, and coal burning	Hair loss, effects on blood chemistry such as decreased blood sugar	• Distillation • Reverse osmosis	0.002 milligram/ liter

See footnotes on page 73.

Table A.1
U.S. EPA Primary Drinking Water Standards (as of May 1994)—*continued*

Organic contaminants	Uses and/or sources	Possible chronic health effects [a]	Possible water treatment methods [b]	Maximum Contaminant Level (MCL) [c]
Acrylamide [d, f]	Used in municipal drinking water treatment, well drilling, food production and processing, paper making, and textile manufacturing; used in grouts and soil stabilizers; also used in photography applications, chromatography gel, dye applications	Probable human carcinogen, nervous system effects	• Activated carbon may be effective	Treatment technique !
Adipate (diethylhexyl)		Possible human carcinogen		0.4 milligram/ liter
Alachlor [d, e]	Agricultural herbicide used in preemergence to field corn, soybeans, and peanuts	Probable human carcinogen; damage to liver, kidney, spleen, and eyes	• Aeration may be effective • Activated carbon has limited effectiveness	0.002 milligram/ liter !
Atrazine [d, e]	Agricultural herbicide used for general weed control	Tremors, organ weight changes, liver damage, heart damage, decrease in body weight gain, miscarriages, possible human carcinogen	• Activated carbon • Cation exchange • Reverse osmosis	0.003 milligram/ liter
Benzo (a) pyrene		Probable human carcinogen		0.0002 milligram/ liter !
Carbofuran [d, e]	Agricultural pesticide	Cholinesterase inhibition[h], reproductive system damage	• Activated carbon • Reverse osmosis	0.04 milligram/ liter
Chlordane [d, e]	Used for termite control; found near hazardous waste sites	Probable human carcinogen, central nervous system effects, liver damage, blood disorders	• Activated carbon	0.002 milligram/ liter !
2,4-D [d, e]	Agricultural herbicide for use on wheat, corn, rangeland, pasture, sorghum, barley, and lawns	Liver and kidney damage, gastrointestinal irritation, decreased fetal weight, blood disorders	• Activated carbon	0.07 milligram/ liter
Dalapon [d, e]	Multipurpose herbicide used to control grasses in crops, drainage ditches, along railroads, and in industrial areas	Changes in kidney weight, decreased fetal weight, toxic to pregnant women	• No information in available literature	0.2 milligram/ liter

See footnotes on page 73.

Table A.1
U.S. EPA Primary Drinking Water Standards (as of May 1994)—*continued*

Organic contaminants	Uses and/or sources	Possible chronic health effects [a]	Possible water treatment methods [b]	Maximum Contaminant Level (MCL) [c]
Di [2-ethylhexyl]-adipate		Possible human carcinogen		0.4 milligram/ liter
Diethylhexyl-phthalate (PAE)		Probable human carcinogen		0.006 milligram/ liter !
Dinoseb [d, e]	Herbicide, desiccant, and dormant fruit spray	Changes in liver and thyroid weights, reduced fertility, reduced fetal weight and survival, developmental abnormalities	• Activated carbon • Anion exchange	0.007 milligram/ liter
Diquat [e]				0.02 milligram/ liter
Endothall [d, e]	Pre- and postemergent herbicide; also a defoliant, desiccant, aquatic algicide, and growth regulator	Unknown	• No information in available literature	0.1 milligram/ liter
Endrin [d, e]	Pesticide registered only for control of cutworms, grasshoppers, and moles	Liver, kidney, brain, and adrenal damage	• Activated carbon • Reverse osmosis	0.002 milligram/ liter
Epichloro-hydrin [d, f]	Used in the manufacture of resins, pharmaceuticals, agricultural chemicals, and rubber products; found in materials used to treat municipal drinking water and liner coatings for water storage tanks	Probable human carcinogen, stomach disorders, infertility, decreased body weight, kidney damage	• No information in available literature	Treatment technique !
Glyphosate [d, e]	Herbicide for control of grasses, broadleaf weeds, and woody brush	Kidney disorders	• No information in available literature	0.7 milligram/ liter
Heptachlor [d, e]	Found in insecticides with very limited use; found near hazardous waste sites	Probable human carcinogen, liver damage, weight loss	• Activated carbon	0.0004 milligram/ liter !
Heptachlor epoxide [d]	Formed by plants and animals after exposure to heptachlor	Probable human carcinogen, liver damage, weight loss	• Activated carbon	0.0002 milligram/ liter !
Hexachloro-benzene [d, e] (HCB)	Fungicide (use discontinued); byproduct of chlorinated chemical production	Probable human carcinogen; liver, kidney, and ovary damage; adrenal and thyroid disorders; skin disorders; decreased fetal weight; nervous system effects; birth defects	• Activated carbon may be effective	0.001 milligram/ liter !

See footnotes on page 73.

Table A.1
U.S. EPA Primary Drinking Water Standards (as of May 1994)—*continued*

Organic contaminants	Uses and/or sources	Possible chronic health effects [a]	Possible water treatment methods [b]	Maximum Contaminant Level (MCL) [c]
Hexachloro-cyclopentadiene				0.05 milligram/ liter
Lindane [d, e]	Found in pesticides for control of wood-inhabiting beetles; used as seed treatment; found in pharmaceutical lotions and shampoos	Liver and kidney damage, possible human carcinogen	• Activated carbon • Reverse osmosis may be effective	0.0002 milligram/ liter
Methoxy-chlor [d, e]	Found in insecticides used in dairy barns for mosquito larvae and horsefly control; registered for use on numerous crops	Growth inhibition, kidney effects	• Activated carbon • Reverse osmosis	0.04 milligram/ liter
Oxamyl [d, e] (Vydate)	Agricultural and horticultural pesticide	Decreased body weight, changes in organ weight	• Adsorption may be effective	0.2 milligram/ liter
Pentachloro-phenol [d, e] (PCP)	Wood preservative, herbicide, antimicrobial agent, disinfectant, mossicide, and defoliant	Probable human carcinogen, liver and kidney damage, reproductive effects	• Activated carbon • Aeration may be effective	0.001 milligram/ liter !
Picloram [d, e]	Herbicide for control of broadleaf and woody plants in rangelands, pastures, and around powerlines and highways	Liver, thyroid, and arterial damage; reduced fertility	• No information in available literature	0.5 milligram/ liter
Polychlorinated biphenyls (PCBs)	Found near hazardous waste sites and disposal and manufacture sites for electrical transformers, electromagnets, fluorescent lights, and plastic	Probable human carcinogen, liver damage	• Activated carbon	0.0005 milligram/ liter !
Simazine [d, e]	Agricultural herbicide used for control of most broadleaf weeds and annual grasses; also used for algae and aquatic weed control in aquariums, ornamental fish ponds, and fountains and for nonselective weed control in industrial areas	Tremors; testicular, kidney, liver, and thyroid damage; severe fetal effects; disturbances in sperm production; possible human carcinogen	• Activated carbon • Cation exchange	0.004 milligram/ liter
2,3,7,8-TCDD [d] (Dioxin)	Byproduct of chlorinated phenolic compound manufacture; no known commercial uses; may exist in fly ash and flue gases of incinerators	Probable human carcinogen, birth defects, reduced fertility, decreased fetal weight	• Activated carbon may be effective	3E-08 milligrams/ liter !
Toxaphene [d, e]	Found in pesticides used to combat worms and insects in cotton and on cattle and sheep	Probable human carcinogen, liver and kidney damage	• Activated carbon • Aeration may be effective	0.003 milligram/ liter !
2,4,5-TP [d, e] (Silvex)	Herbicide used for corn, soybeans, sugarcane, and wheat	Liver, heart, and kidney damage; affects nervous, respiratory, reproductive systems	• Activated carbon	0.05 milligram/ liter

See footnotes on page 73.

Table A.1
U.S. EPA Primary Drinking Water Standards (as of May 1994)—*continued*

Volatile organic contaminants	Uses and/or sources	Possible chronic health effects [a]	Possible water treatment methods [b]	Maximum Contaminant Level (MCL) [c]
Benzene [d, e]	Found near leaking underground fuel storage tanks and industrial waste sites; used in the manufacture of pesticides, detergents, and solvents; used in petroleum refining and coal processing; added to gasoline to increase octane	Cancer, including leukemia; blood disorders; inhibited fetal growth; immune system depression	• Activated carbon • Aeration • Boiling	0.005 milligram/ liter !
Carbon tetra-chloride [d, e]	Used in the manufacture of chlorofluorocarbons (a refrigerant, foam-blowing agent, and solvent); also used in grain fumigants, fire extinguishers, cleaning agents, dry cleaning operations, and paint and plastic manufacture; found near chemical disposal sites	Probable human carcinogen, liver damage	• Activated carbon • Aeration • Boiling	0.005 milligram/ liter !
Dibromochloro-propane [d, e] (DBCP)	Soil fumigant	Probable human carcinogen, kidney damage, infertility, reduced body weight	• Activated carbon • Aeration	0.0002 milligram/ liter !
m-Dichloro-benzene [d, i]		Liver, spleen, and kidney damage	• Activated carbon • Aeration	0.6 milligram/ liter
o-Dichloro-benzene [d]	Used in the manufacture of solvents, deodorizers, and chemicals	Liver, spleen, and kidney damage	• Activated carbon • Aeration	0.6 milligram/ liter
p-Dichloro-benzene [d, e]	Deodorizer, insecticide, moth repellent	Liver, spleen, and kidney damage; possible human carcinogen	• Activated carbon • Aeration	0.075 milligram/ liter
1,2-Dichloro-ethane [d]	Used in vinyl chloride manufacturing; also used in metal degreasers, adhesives, grain fumigants, and soaps and scouring compounds; used as gasoline additive, dry cleaning solvent, and varnish and finish remover	Probable human carcinogen; kidney, heart, and liver damage	• Activated carbon • Aeration • Boiling	0.005 milligram/ liter !
1,1-Dichloro-ethylene [d]	Used in the manufacture of food packaging films and coatings, chemicals, and polymers	Liver damage, mutagenic effects, possible human carcinogen	• Activated carbon • Aeration	0.007 milligram/ liter
cis-1,2-Dichloro-ethylene [d]	Used in the manufacture of solvents and organic chemicals; usually transformed in drinking water from other chlorinated hydrocarbons	Liver effects	• Activated carbon • Aeration • Boiling	0.07 milligram/ liter
trans-1,2-Dichloro-ethylene [d]	Used in the manufacture of chemical solvents and organic chemicals; usually transformed in drinking water from other chlorinated hydrocarbons	Liver effects	• Activated carbon • Aeration	0.1 milligram/ liter

See footnotes on page 73.

Table A.1
U.S. EPA Primary Drinking Water Standards (as of May 1994)—*continued*

Volatile organic contaminants	Uses and/or sources	Possible chronic health effects [a]	Possible water treatment methods [b]	Maximum Contaminant Level (MCL) [c]
Dichloro-methane [d]	Used as a solvent for insecticides, paints, varnishes, and paint removers; used in food processing, degreasing, and cleaning fluids; large amounts disposed of in landfills, dumps, and sewers (more common near urban areas)	Probable human carcinogen, liver damage, blood disorders	• Activated carbon • Aeration	0.005 milligram/ liter !
1,2-Dichloro-propane [d]	Used as industrial solvent for oils and fats; used in dry cleaning and degreasing fluid components, soil fumigants, and organic chemical production	Probable human carcinogen, liver damage	• Activated carbon • Ion exchange • Boiling • Aeration may be effective	0.005 milligram/ liter !
Ethylbenzene [d]	Used in the manufacture of styrene, acetophenone, and solvents; present in asphalt and naphtha; found in gasoline	Liver and kidney damage	• Aeration • Activated carbon at least partially effective	0.7 milligram/ liter
Ethylene dibromide [d, e] (EDB)	Pesticide; fumigant for soil, grains, and fruit; used in leaded gasoline additives (all uses canceled in 1983)	Probable human carcinogen, liver and kidney damage, stomach and reproductive system effects, mutagenic effects	• Activated carbon • Aeration • Boiling	0.00005 milligram/ liter !
Monochloro-benzene [d]	Used as a solvent in the manufacture of rubber, adhesives, paints, waxes, and polishes	Liver, spleen, and kidney effects	• Activated carbon • Aeration • Reverse osmosis • Boiling	0.1 milligram/ liter
Styrene [d, e]	Used in the manufacture of plastics; found in pesticide products *	Liver and kidney effects, decreased weight gain, possible human carcinogen	• Aeration • Activated carbon	0.1 milligram/ liter
Tetrachloro-ethylene [d]	Used as industrial metal, textile, and dry cleaning solvent; used in the manufacture of fluorocarbons	Probable human carcinogen, liver effects	• Activated carbon • Aeration • Boiling	0.005 milligram/ liter !
Toluene [d]	Used as a solvent in the manufacture of paint, oil, and resins; found near leaking fuel storage tanks; used in organic chemical production; gasoline additive	Birth defects, higher fetal mortality, blood disorders	• Aeration • Activated carbon	1.0 milligram/ liter
1,2,4-Trichloro-benzene [d]	Solvent used in chemical manufacturing; used in dyes, dielectric fluids, transformer oils, lubricants, heat-transfer media, and insecticides	Liver and urinary tract disorders	• Activated carbon • Aeration • Reverse osmosis	0.07 milligram/ liter

See footnotes on page 73.

Table A.1
U.S. EPA Primary Drinking Water Standards (as of May 1994)—*continued*

Volatile organic contaminants	Uses and/or sources	Possible chronic health effects [a]	Possible water treatment methods [b]	Maximum Contaminant Level (MCL) [c]
1,1,1-Trichloroethane [d, e]	Found near hazardous waste sites; found in industrial solvents and degreasers; additive in metal-cutting oil; used in the manufacture of organic chemicals and pesticide products*; used as spot remover and film cleaner	Liver effects, diminished weight gain, central nervous system disorders	• Activated carbon • Aeration • Boiling • Reverse osmosis may be effective	0.2 milligram/ liter
1,1,2-Trichloroethane [d]	Used in the production of 1-1-dichloroethylene; used as a solvent for chlorinated rubbers; found in fats, oils, waxes, and resins	Lung and liver damage, effects on immune system, blood disorders in females, possible human carcinogen	• Activated carbon • Aeration or reverse osmosis may be effective	0.005 milligram/ liter
Trichloroethylene [d] (TCE)	Found near hazardous waste sites; used in solvents and metal degreasers	Probable human carcinogen, liver effects	• Activated carbon • Aeration • Boiling	0.005 milligram/ liter !
Vinyl chloride [d]	Used in the manufacture of plastics, glass, paper, and synthetic rubber; results from corrosion of plastic pipes; used in soldering and in the automotive industry; also used in the manufacture of electrical wire insulation and cables, piping, medical supplies, food packaging, and building and construction products	Cancer, liver damage	• Aeration • Activated carbon may be effective	0.002 milligram/ liter !
Xylenes [d]	Found near leaking underground fuel storage tanks; used in solvents for paint, inks, and adhesives; component of detergents for industrial and household products; component of petroleum oil and product of gasoline refining	Nervous system effects, liver damage, toxic to fetuses	• Activated carbon • Aeration	10.0 milligrams/ liter

See footnotes on page 73.

Table A.1
U.S. EPA Primary Drinking Water Standards (as of May 1994)—*continued*

Source: Maximum Contaminant Levels (MCLs) are taken from *Drinking Water Regulations and Health Advisories,* Office of Water, U.S. Environmental Protection Agency (EPA), Washington, D.C. (May 1994). Uses and/or sources (except those marked with an asterisk), possible chronic health effects, and possible water treatment methods all excerpted from various health advisories published on various dates by the EPA Office of Water. Uses and/or sources marked with an asterisk excerpted with permission from the *1994 Farm Chemicals Handbook,* Meister Publishing Company.

[a] Chronic health effects occur from ingesting small amounts of the contaminant over long periods of time. Daily consumption of water with a contaminant concentration well above the Maximum Contaminant Level (MCL) over a long period of time increases the risk of the listed health effects. In determining MCLs, the U.S. Environmental Protection Agency assumes that a person consumes 2 liters of water per day.

[b] Selection of individual or combinations of technologies to attempt contaminant reduction must be based on a case-by-case technical evaluation, and on an assessment of the economics involved. Boiling is occasionally listed as a possible treatment technique for volatile organic contaminants. Boiling is a short-term, emergency treatment only, as health effects may result from inhalation of a contaminant when it escapes from water. Reverse osmosis is also occasionally listed as a possible treatment technique for organic or volatile organic contaminants. In some health advisories, the operating pressure used in tests of reverse osmosis systems ranged from 300 to 1,000 pounds per square inch, which is far above normal household water pressure. See page 19 for more information on reverse osmosis.

[c] Water with a contaminant concentration at or below the Maximum Contaminant Level (MCL) is acceptable for drinking every day over a lifetime and does not pose any health concerns unless the MCL is marked with a "**!**". For these contaminants, the U.S. Environmental Protection Agency (EPA) assumes that there is no risk-free dose, as the contaminant is a known or probable carcinogen. The MCL is set as close to zero as is feasible based on current water treatment technologies and the means available to measure the concentration of the contaminant in water.

[d] A document is available from the U.S. Environmental Protection Agency (EPA) Office of Water that details the formation of the standard for this contaminant. The document includes information about the contaminant's physical properties and its behavior in the environment; detailed accounts of short-term and long-term exposure studies involving humans and/or laboratory animals and the health effects that resulted from such studies; and calculations for a one-day, ten-day, and longer-term health advisory for a 10-kilogram child, as well as for a longer-term and lifetime health advisory for a 70-kilogram adult. The document will also have more information concerning the possible water treatment methods listed in this table. For information about ordering such a document, contact the EPA Office of Water at 202-260-7571, or call the EPA Safe Drinking Water Hotline at 1-800-426-4791.

[e] This contaminant is an ingredient in some pesticide products and therefore may be distributed under several different product names. See appendix C, table C.1, for a list of product names.

[f] The Maximum Contaminant Level (MCL) for this contaminant is listed as "treatment technique." As discussed in the introduction to this publication, the primary drinking water standards are developed for municipal water supplies. "Treatment technique" indicates that municipal water treatment facilities should alter their treatment systems until contaminant levels fall below the action level set by the U.S. Environmental Protection Agency (EPA). When water corrodes pipes and causes lead or copper contamination, a treatment technique may be required to make the water noncorrosive. For acrylamide, treatment technique indicates that the municipality should minimize the amount of acrylamide used in water treatment. For more information, contact the EPA.

[g] Fluoride concentrations in the range of 1.0 milligram per liter are desirable in drinking water for protection against tooth decay. For this reason, fluoride may be added to a municipal water supply. The actual optimum concentration is related to average daily air temperatures at the location. See also appendix B.

[h] Cholinesterase inhibition may cause nausea, blurred vision, stomach cramps, excessive sweating, muscle weakness, headaches, and rapid heart rate.

[i] The values for m-dichlorobenzene are based on data for o-dichlorobenzene.

[!] See footnote "c."

Table A.2
Selected contaminants for which U.S. EPA health advisories have been issued (as of May 1994)

Inorganic contaminants	Uses and/or sources	Possible chronic health effects [a]	Possible water treatment methods [b]	Lifetime Health Advisory Level [c] (milligrams/liter)
Ammonia [d]	Used in fertilizers, refrigeration systems, and manufacturing processes; used in conjunction with chlorine to form chloramine	None documented	• Eliminated when drinking water is chlorinated • Aeration • Reverse osmosis • Cation exchange	30.0 (based on taste and odor)
Arsenic [e]	Occurs in rocks and soil; found in pesticide residues; byproduct of smelting (especially copper), glass making, and coal mining	Cancer, vascular disorders	• Activated alumina • Anion exchange • Reverse osmosis • Distillation	0.05 milligram/ liter !
Boron [d, e]	May be used in composite structural materials, abrasives, alloys, steelmaking, glass manufacture, cleaners, wood and leather preservatives, flame retardants, cosmetics, insecticides for cockroach and black carpet beetle control, metal refining, and rocket fuels	Testicular atrophy; liver, kidney, and spleen effects; decreased sperm count; reduced fertility	• Reverse osmosis • Anion exchange • Activated carbon • Distillation	0.6
Cyanide [e]	Used in rat and pest poisons, photographic solutions, fumigating products, resin production, and electroplating	Thyroid and neurological disorders, toxic to fetuses	• Chlorination • Anion exchange • Reverse osmosis	0.2
Silver [d]	Used extensively in photographic processing, mirror production, and dental alloys; used in coinage, food processing, inks and dyes, and the manufacture of tableware, jewelry, solder, alloys, and batteries	Skin discoloration, kidney and eye effects	• Reverse osmosis • Distillation	0.1
White phosphorus	Used in military screening smoke and incendiary devices; used in the manufacture of phosphorous compounds, semiconductors, and electroluminescent coatings	Liver damage, bone disorders, childbirth complications, weight loss	• Aeration • Ozonation • Chlorination and other oxidation processes	0.0001
Zinc and zinc chloride measured as zinc [e]	Used in the manufacture of galvanized steel and organic chemicals; occurs naturally in the earth's crust; used in wood preservatives, batteries, soldering, military screening smoke, textiles, adhesives, embalming fluids, pesticide products*, and deodorants	Anemia, birth defects	• Reverse osmosis • Distillation	2.0

See footnotes on page 85.

Table A.2
Selected contaminants for which U.S. EPA health advisories have been issued (as of May 1994)—*continued*

Organic contaminants	Uses and/or sources	Possible chronic health effects [a]	Possible water treatment methods [b]	Lifetime Health Advisory Level [c] (milligrams/liter)
Acifluorfen [e]	Pre- and postemergent agricultural herbicide used to control weeds and grasses in large-seeded legumes including soybeans and peanuts	Probable human carcinogen; heart, liver, and kidney damage; blood disorders; delayed fetal development	• Reverse osmosis	0.001 !
Aldicarb [d, e]	Agricultural pesticide	Cholinesterase inhibition [f]	• Activated carbon	0.007
Aldicarb sulfone [d, e]	Formed by plants and animals after exposure to aldicarb; found in pesticide products*	Cholinesterase inhibition [f]	• Activated carbon	0.007
Aldicarb sulfoxide [d]	Formed by plants and animals after exposure to aldicarb	Cholinesterase inhibition [f]	• Activated carbon	0.007
Aldrin [d, e]	Insecticide for soil-dwelling pests; also used for termite and ant control (all uses discontinued in 1974)	Probable human carcinogen, liver and kidney effects, weight loss, loss of muscle control, developmental effects	• Activated carbon • Reverse osmosis	0.000002 !
Ametryn [e]	Agricultural herbicide for control of broadleaf and grass weeds in pineapple, sugarcane, bananas, and plantains; also used on corn and potato vines	Liver damage	• Activated carbon	0.06
Ammonium sulfamate [e]	Agricultural herbicide used to control woody plants; may be used on poison ivy in apple and pear orchards	Reduced weight gain	• No information in available literature	2.0
Baygon [e]	Insecticide used on lawns, ornamentals, forests, anthills; also used in gypsy moth traps and fly strips, pet flea collars, and flea shampoos; used on stagnant waters	Liver damage, nervous system damage, decreased weight gain, cholinesterase inhibition [f], possible human carcinogen	• Activated carbon	0.003
Bentazon [e]	Agricultural herbicide used to control broadleaf weeds in soybeans, rice, corn, peanuts, dry beans, dry peas, snap beans, lima beans, and mint	Excessive weight loss, inflammation of the prostate gland	• No information in available literature	0.02

See footnotes on page 85.

Table A.2
Selected contaminants for which U.S. EPA health advisories have been issued (as of May 1994)—*continued*

Organic contaminants	Uses and/or sources	Possible chronic health effects [a]	Possible water treatment methods [b]	Lifetime Health Advisory Level [c] (milligrams/liter)
Bromacil [e]	Herbicide used for general weed and brush control in noncrop areas; also used against perennial grasses	Testicular, liver, and thyroid damage; decreased weight gain; possible human carcinogen	• No information in available literature	0.09
Carbaryl [e]	Insecticide used on crops, forests, lawns, ornamentals, shade trees, and rangelands	Liver and kidney damage, reduced fertility, delayed fetal development, cholinesterase inhibition [f]	• Activated carbon	0.7
Carboxin [e]	Seed protectant; wood preservative; used to control fungus	Kidney and liver damage	• No information in available literature	0.7
Chloramben [e]	Agricultural herbicide	Liver damage	• Activated carbon and ion exchange may be effective	0.1
Chlorothalonil [e]	Agricultural pesticide for fungus control	Probable human carcinogen, kidney damage, toxic to fetuses	• Reverse osmosis	0.0015 !
Chlorpyrifos [e]	Broad-spectrum insecticide for use on corn and cotton; also used by commercial pest-control and lawn-and-garden services; used for domestic household and lawn-and-garden applications	Weight loss and decreased weight gain, reduced fetal body weight, developmental effects, cholinesterase inhibition [f]	• Activated carbon may be effective	0.02
Cyanazine [d, e]	Herbicide for use on annual grasses and broadleaf weeds	Blood disorders, birth defects, liver effects, body weight changes, possible human carcinogen	• Activated carbon	0.001
Dacthal [e] (DCPA)	Preemergent herbicide for use on turf, ornamentals, strawberries, vegetables, cotton, soybeans, and field beans	Thyroid, spleen, liver, and kidney disorders	• Reverse osmosis	4.0
Diazinon [e]	Soil insecticide used on fruits, vegetables, tobacco, forage crops, ornamentals, rangeland, and pasture; also used as a seed treatment and nematocide for turf	Central nervous system depression, skin disorders, cholinesterase inhibition [f]	• Reverse osmosis • Activated carbon	0.0006
Dicamba [e]	Multipurpose herbicide for control of broadleaf weeds in various agricultural crops and along fencerows, roads, and rangeland; also used to control brush and vines	Liver damage, decreased body weight, toxic to fetuses and pregnant women	• Activated carbon	0.2

See footnotes on page 85.

Table A.2
Selected contaminants for which U.S. EPA health advisories have been issued (as of May 1994)—*continued*

Organic contaminants	Uses and/or sources	Possible chronic health effects [a]	Possible water treatment methods [b]	Lifetime Health Advisory Level [c] (milligrams/liter)
Dieldrin [e]	Multipurpose pesticide (manufacture and all uses discontinued)	Probable human carcinogen, liver damage, convulsions, chromosome abnormalities, fetal weight loss, birth defects	• Reverse osmosis • Activated carbon	0.000002 !
Diisopropyl methyl-phosphonate (DIMP)	Byproduct of nerve gas manufacture	Gastrointestinal disorders, skin disorders	• Activated carbon may be effective	0.6
Dimethrin	Insecticide used in ponds and swamps on mosquito larvae	Liver and kidney disorders, reduction in body weight	• No information in available literature	2.0
1,3-Dinitro-benzene (DNT)	Byproduct of nitrobenzene and TNT manufacture; used in dye production	Spleen and testicular disorders	• No information concerning home water treatment methods in available literature	0.001
2,4-Dinitro-toluene [g]	Used in the manufacture of munitions, explosives, dyes, and polyurethane	Probable human carcinogen, weight loss, blood disorders, bile system disorders, atrophy of ovaries and testes, low fetal weight and survival, paralysis and incoordination	• Activated carbon	0.00005 !
2,6-Dinitro-toluene [g]	Used in the manufacture of munitions, explosives, dyes, and polyurethane	Probable human carcinogen, weight loss, blood disorders, bile system disorders, kidney damage, atrophy of testes, incoordination and paralysis	• Activated carbon	0.00005 !
Diphenamid [e]	Preemergent and selective agricultural herbicide used on tomatoes, peanuts, alfalfa, soybeans, cotton, and other crops	Liver and thyroid damage	• Activated carbon	0.2
Diphenyl-amine [e] (DPA)	Pesticide used in the preservation of fruits, vegetables, and flowers; used in the manufacture of dyes, explosives, and munitions; used in the production of antioxidants for rubber, greases, and oils	Kidney and liver damage, blood disorders, anemia, fetal kidney disorders, decreased weight gain	• Activated carbon may be effective	0.2

See footnotes on page 85.

Table A.2
Selected contaminants for which U.S. EPA health advisories have been issued (as of May 1994)—*continued*

Organic contaminants	Uses and/or sources	Possible chronic health effects [a]	Possible water treatment methods [b]	Lifetime Health Advisory Level [c] (milligrams/liter)
Disulfoton [e]	Insecticide	Organ weight changes, eye damage, birth defects, cholinesterase inhibition [f]	• No information in available literature	0.0003
Diuron [e]	Agricultural herbicide used to control broadleaf and grass weeds in various crops; also used as a soil sterilant	Spleen and liver damage, abnormal fetal development, methemoglobinemia (blue baby syndrome), reduced body weight, blood disorders	• Activated carbon	0.01
Ethylene glycol [h]	Antifreeze; used as a solvent in paint, plastic, and ink production; used in the manufacture of electrolytic condensors	Kidney disorders, birth defects, toxic to pregnant women	• No information in available literature	7.0
Ethylene thiourea (ETU)	Results from the breakdown of EBDC (ethylene bisdithiocarbamate) pesticides (pesticides used for fungus control on flowers and a wide range of crops)	Probable human carcinogen, thyroid damage, genetic mutations, birth defects		0.0003 !
Fenamiphos [e]	Agricultural and horticultural nematocide	Reduced maternal weight gain, reduced fetal weight and survival, abnormalities in fetal bone development, cholinesterase inhibition [f]	• No information in available literature	0.002
Fluometuron [e]	Herbicide for control of annual grasses and broadleaf weeds in cotton and sugarcane	Liver, spleen, and kidney damage; decreased body weight	• Activated carbon	0.09
Hexazinone [e]	Multipurpose herbicide used on coniferous trees around utilities, drainage ditches, and railroad beds; sugar; and alfalfa	Liver and chromosome damage, blood disorders, reduced body weight in adults and offspring, decreased body weight gain	• No information in available literature	0.2
HMX	Used in the manufacture of munitions, explosives, rocket fuel, and nuclear weapons	Liver and kidney disorders	• Activated carbon	0.4

See footnotes on page 85.

Table A.2
Selected contaminants for which U.S. EPA health advisories have been issued (as of May 1994)—*continued*

Organic contaminants	Uses and/or sources	Possible chronic health effects [a]	Possible water treatment methods [b]	Lifetime Health Advisory Level [c] (milligrams/liter)
Isophorone	Used as a solvent in lacquers, resins, pesticides, herbicides, fats, oils, and gums; used in the manufacture of solvents and plant growth retardants; woodpecker repellant	Possible human carcinogen	• Activated carbon	0.04
Isopropyl methyl-phosphonate [d]	Degradation product of the nerve gas Sarin; metabolite of diisopropyl methyl phosphonate (DIMP)	Unknown	• No information in available literature	0.7
Malathion [e]	Insecticide used extensively to control a wide variety of insects and mites; used for industrial, commercial, domestic, agricultural, and government applications	Cholinesterase inhibition [f]	• Activated carbon	0.2
Maleic hydrazide [e]	Plant growth retardant; found in pesticide products*	Effects on body weight, kidney disorders	• No information in available literature	4.0
MCPA [e]	Herbicide used to control annual and perennial weeds in cereals, grasslands, and turf	Kidney, liver, and blood disorders; low fetal weight	• No information in available literature	0.01
Methomyl [e]	Agricultural and horticultural insecticide	Adverse effects on kidney, spleen, liver, and bone marrow; central nervous system damage; cholinesterase inhibition [f]	• Activated carbon	0.2
Methyl parathion [e]	Restricted-use agricultural pesticide used especially for boll weevil	Retinal degeneration, birth defects, decreased body weight, cholinesterase inhibition [f]	• Activated carbon • Reverse osmosis	0.002
Metolachlor [e]	Agricultural and horticultural herbicide for use on corn, soybeans, peanuts, grain sorghum, pod crops, cotton, safflower, woody ornamentals, sunflowers, and flax	Testicular damage, decreased weight, possible human carcinogen	• Activated carbon may be effective	0.1
Metribuzin [e]	Agricultural herbicide used to control grass and broadleaf weeds	Kidney damage; liver, heart, and thyroid effects; decreased body weight	• Activated carbon	0.2
Nitroguanidine (NQ)	Used in the manufacture of military munitions	Heart and liver disorders, weight loss, reduced fetal body weight	• Activated carbon • Cation exchange may be effective	0.7

See footnotes on page 85.

Table A.2
Selected contaminants for which U.S. EPA health advisories have been issued (as of May 1994)—*continued*

Organic contaminants	Uses and/or sources	Possible chronic health effects [a]	Possible water treatment methods [b]	Lifetime Health Advisory Level [c] (milligrams/liter)
p-Nitrophenol	Used in the manufacture of pesticides, dyes, fungicides, and leather preservatives	Lung, liver, and kidney effects; reduced maternal weight gain	• No information in available literature	0.06
Paraquat [e]	Widely used agricultural herbicide and desiccant	Kidney and lung disorders, reduced fetal weight gain, weight loss	• Activated carbon • Cation exchange may be effective	0.03
Prometon [e]	Herbicide for control of perennial broadleaf weeds and grasses	Adverse effects on growth	• Activated carbon	0.1
Pronamide [e]	Agricultural and horticultural herbicide used on legumes, southern turf, greens, woody ornamentals, nursery stock, and Christmas trees	Liver damage, decreased weight gain, possible human carcinogen	• Reverse osmosis may be effective	0.05
Propachlor [e]	Herbicide for control of many grasses and certain broadleaf weeds	Liver and kidney damage, blood disorders, fetal development disorders, decreased body weight gain	• Activated carbon or reverse osmosis may be effective	0.09
Propazine [e]	Agricultural herbicide used to control most annual broadleaf weeds and annual grasses in milo and sweet sorghum	Weight loss and decreased weight gain, delayed fetal bone development, possible human carcinogen	• No information in available literature	0.01
Propham [e]	Agricultural herbicide for use on various field crops, produce, and fallow land	Spleen effects, delayed fetal development, reduced fetal body weight, cholinesterase inhibition [f]	• Activated carbon	0.1
RDX	Used in the manufacture of military munitions and explosives; used as rat poison	Anemia, central nervous system effects, kidney and liver damage, prostate inflammation, testicular degeneration, weight loss, birth defects, reduced fetal weight, possible human carcinogen	• Ion exchange and activated carbon may be effective	0.0003

See footnotes on page 85.

Table A.2
Selected contaminants for which U.S. EPA health advisories have been issued (as of May 1994)—*continued*

Organic contaminants	Uses and/or sources	Possible chronic health effects [a]	Possible water treatment methods [b]	Lifetime Health Advisory Level [c] (milligrams/liter)
2,4,5-T [e]	Herbicide used to control woody plants and weeds on industrial sites and rangeland; used for weed control in rice	Kidney, liver, and urinary tract disorders; weight loss; decrease in body weight gain; birth defects	• Activated carbon • Ion exchange may be effective	0.07
Tebuthiuron [e]	Woody plant herbicide used in noncropland areas; used for brush and weed control in rangeland	Excessive weight loss, pancreas damage	• No information in available literature	0.5
Terbacil [e]	Agricultural herbicide used to control annual and perennial weeds in sugarcane, alfalfa, pecans, mint, and various fruits	Liver effects, decreased body weight gain, disturbances in fetal development, toxic to pregnant women	• No information in available literature	0.09
Terbufos [e]	Agricultural pesticide used to control corn rootworm, other soil insects, and nematodes infesting corn; sugarbeet maggots in sugarbeets; and green bug in grain sorghum	Liver effects, eye and stomach damage, disturbances in fetal development, cholinesterase inhibition [f]	• Activated carbon may be effective	0.0009
Trinitroglycerol (TNG)	Commercial explosive	Liver, spleen, and blood disorders; decreased appetite and corresponding weight loss; impaired fertility; methemoglobinemia (blue baby syndrome)	• No information in available literature	0.005
Trinitrotoluene (TNT)	Military explosive	Bone marrow, kidney, and spleen disorders; inflammation of the liver and bladder; anemia; testicular atrophy and other testicular effects; reduced appetite and corresponding weight loss; possible human carcinogen	• No information in available literature	0.001

See footnotes on page 85.

Table A.2
Selected contaminants for which U.S. EPA health advisories have been issued (as of May 1994)—*continued*

Volatile organic contaminants	Uses and/or sources	Possible chronic health effects [a]	Possible water treatment methods [b]	Lifetime Health Advisory Level [c] (milligrams/liter)
Bis-2-chloro-isopropyl ether	Solvent for fat, waxes, and greases; used in textile manufacture, cleaning solutions, and paint and varnish removers	Blood disorders, weight loss or decreased weight gain, chromosomal aberrations	• Activated carbon • Aeration may be effective	0.3
Bromochloro-methane	Fire extinguisher fluid	Liver and kidney disorders, reduced food consumption	• Aeration	0.09
Bromo-methane [e]	Soil fumigant for fungi, nematode, and weed control; used in dye manufacture; solvent for extracting oil from nuts, flowers, and seeds; wool degreaser; space fumigant to control insects and rodents in food storage facilities	Stomach disorders, decreased food consumption	• Aeration • Activated carbon may be effective	0.01
Butylate [e]	Agricultural herbicide	Testicular and liver damage, delayed fetal development, reduced body weight	• No information in available literature	0.35
Chloromethane	Used in the production of chemicals (primarily silicones, tetramethyl lead, and methyl cellulose); also used in herbicides	Neurological disorders, possible human carcinogen	• Aeration • Activated carbon may be effective	0.003
o-Chlorotoluene	Solvent and intermediate used in the manufacture of pesticides, dyes, pharmaceuticals, and peroxides	Blood disorders; heart, adrenal, and testicular disorders; weight loss	• Aeration • Activated carbon may be effective	0.1
p-Chlorotoluene	Solvent and intermediate used in the manufacture of pesticides, dyes, pharmaceuticals, and peroxides	Blood disorders; heart, adrenal, and testicular disorders; weight loss	• Aeration • Activated carbon	0.1
Dichlorodi-fluoromethane	Air conditioning refrigerant; food freezant	Decreased weight gain	• Aeration	1.0
1,3-Dichloro-propene [e]	Soil fumigant used primarily on sandy soils	Probable human carcinogen, kidney and bladder effects, decreased maternal weight gain, effects on nasal tissue and stomach	• Activated carbon may be effective	0.0002 !
Dimethylmethyl-phosphonate (DMMP)	Used in flame retardants, epoxy resins, acrylic latex, unsaturated polyester, urethane coatings, urethane rigid foam, and vinyl; also used in nerve gas testing	Liver effects, decreased body weight, reproductive disorders, slowed fetal development, possible human carcinogen	• Activated carbon may be effective	0.007

See footnotes on page 85.

Table A.2
Selected contaminants for which U.S. EPA health advisories have been issued (as of May 1994)—*continued*

Volatile organic contaminants	Uses and/or sources	Possible chronic health effects [a]	Possible water treatment methods [b]	Lifetime Health Advisory Level [c] (milligrams/liter)
p-Dioxane	Solvent used in the production of cellulose acetate, resins, oils, and waxes	Probable human carcinogen, liver and kidney damage	• Activated carbon	0.007 !
1,4-Dithiane	Byproduct of mustard gas degradation	Liver and kidney damage, nasal lesions	• No information in available literature	0.08
Fluorotrichloro-methane	Used in the manufacture of plastic foam; refrigerant; solvent/degreasing agent used in the aerospace and electronics industries; used in fire extinguishers	Unknown	• Activated carbon • Aeration	2.0
Fonofos [e]	Soil insecticide	Cholinesterase inhibition [f]	• No information in available literature	0.01
Hexachloro-butadiene	Pesticide; solvent in chlorine gas production; used in the manufacture of rubber compounds and lubricants	Kidney and liver disorders, decreased body weight in offspring, birth defects, possible human carcinogen	• Activated carbon • Aeration	0.001
Hexachloro-ethane	Used in military pyrotechnic devices and screening smoke; used in the production of fluorocarbons for dry-cleaning chemicals, aerosols, and refrigerants; exists in lubricants, insecticides, rodenticides, moth repellents, and fire-extinguishing fluids	Liver and kidney disorders, slowed fetal development, weight loss, possible human carcinogen	• Aeration may be effective	0.001
n-Hexane	Solvent used in glues, varnishes, cements, and inks; used to extract oil from seeds such as soybean and cotton seeds	Neurological disorders, testicular atrophy, decreased body weight	• Boiling • Activated carbon and aeration may be effective	Not available
Naphthalene [e]	Moth repellant; insecticide; vermicide; used in the production of dyes, resins, lampblack, celluloid, and smokeless gunpowder	Blood disorders; kidney damage; liver, brain, and spleen disorders; toxic to fetuses and pregnant women; reduced weight gain	• Activated carbon • Aeration	0.02
Phenol [d]	Used as a disinfectant, antiseptic, bactericide, and antimicrobial agent; used in the manufacture of resins and medical and industrial compounds and dyes; solvent in petroleum refining	Reduced fetal body weight, depressed body weight gain, toxic to pregnant women	• Activated carbon • Aeration may be effective	4.0

See footnotes on page 85.

Table A.2
Selected contaminants for which U.S. EPA health advisories have been issued (as of May 1994)—*continued*

Volatile organic contaminants	Uses and/or sources	Possible chronic health effects [a]	Possible water treatment methods [b]	Lifetime Health Advisory Level [c] (milligrams/liter)
1,1,1,2-Tetra-chloroethane	Used in the production of chemical solvents	Liver and kidney damage, decreased body weight gain, lung damage, toxic to fetuses, possible human carcinogen	• Aeration • Activated carbon may be effective	0.001
1,3,5-Trichloro-benzene	Used in the manufacture of explosives, pesticides, and electrical insulation	Respiratory and urinary tract disorders	• Activated carbon • Aeration may be effective	0.04
Trifluralin [e]	Herbicide for control of annual grasses and broadleaf weeds; used in agriculture and on golf courses, rights of way, and domestic outdoor and industrial areas	Liver, spleen, and kidney damage; blood disorders; decreased fetal weight and size; increased incidence of miscarriages; decreased weight gain; possible human carcinogen	• Activated carbon • Aeration may be effective	0.005

See footnotes on page 85.

Table A.2
Selected contaminants for which U.S. EPA health advisories have been issued (as of May 1994)—*continued*

Source: Lifetime Health Advisory Levels are taken from *Drinking Water Regulations and Health Advisories,* Office of Water, U.S. Environmental Protection Agency (EPA), Washington, D.C. (May 1994). Uses and/or sources (except those marked with an asterisk), possible chronic health effects, and possible water treatment methods all excerpted from various health advisories published on various dates by the EPA Office of Water. Uses and/or sources marked with an asterisk excerpted with permission from the *1994 Farm Chemicals Handbook,* Meister Publishing Company.

Note: A document is available from the U.S. Environmental Protection Agency Office of Water that details the formation of the health advisory for each of the contaminants in this table. The document includes information about the contaminant's physical properties and its behavior in the environment; detailed accounts of short-term and long-term exposure studies involving humans and/or laboratory animals and the health effects that resulted from such studies; and calculations for a one-day, ten-day, and longer-term health advisory for a 10-kilogram child, as well as for a longer-term and lifetime health advisory for a 70-kilogram adult. The document will also have more information concerning the possible water treatment methods listed in this table. For information about ordering such a document, contact the EPA Office of Water at 202-260-7571, or call the EPA Safe Drinking Water Hotline at 1-800-426-4791.

[a] Chronic health effects occur from ingesting small amounts of the contaminant over long periods of time. Daily consumption of water with a contaminant concentration well above the Lifetime Health Advisory Level over a long period of time increases the risk of the listed health effects. In determining Lifetime Health Advisory Levels, the U.S. Environmental Protection Agency assumes that a person consumes 2 liters of water per day.

[b] Selection of individual or combinations of technologies to attempt contaminant reduction must be based on a case-by-case technical evaluation, and on an assessment of the economics involved. Boiling is occasionally listed as a possible treatment technique for volatile organic contaminants. Boiling is a short-term, emergency treatment only, as health effects may result from inhalation of a contaminant when it escapes from water. Reverse osmosis is also occasionally listed as a possible treatment technique for organic or volatile organic contaminants. In some health advisories, the operating pressure used in tests of reverse osmosis systems ranged from 300 to 1,000 pounds per square inch, which is far above normal household water pressure. See page 19 for more information on reverse osmosis.

[c] Water with a contaminant concentration at or below the Lifetime Health Advisory Level is acceptable for drinking every day over a lifetime and does not pose any health concerns unless the Lifetime Health Advisory Level is marked with a "**!**". For these contaminants, the U.S. Environmental Protection Agency assumes that there is no risk-free dose, as the contaminant is a known or probable carcinogen. Daily consumption of water with a carcinogenic contaminant concentration equal to the Lifetime Health Advisory Level will theoretically result in a one-in-a-million chance of developing cancer as a direct result of ingesting the contaminant.

[d] The information listed for this contaminant is taken from a draft health advisory.

[e] This contaminant is an ingredient in some pesticide products and therefore may be distributed under several different product names. See appendix C, table C.1, for a list of product names.

[f] Cholinesterase inhibition may cause nausea, blurred vision, stomach cramps, excessive sweating, muscle weakness, headaches, and rapid heart rate.

[g] Dinitrotoluene exists as a mixture of two or more of its six isomers; 2,4-dinitrotoluene and 2,6-dinitrotoluene are the most predominant isomers. The health advisory is based on technical-grade dinitrotoluene, which is composed of 76 percent 2,4-dinitrotoluene, 19 percent 2,6-dinitrotoluene, and 5 percent other dinitrotoluene isomers.

[h] If ethylene glycol is misused as an antifreeze in potable water supplies, flush the distribution system vigorously.

[!] See footnote "c."

Table A.3
Additional U.S. EPA drinking water contaminants for which documentation is unavailable (as of May 1994)

Organic contaminants	Advisory level [a] (milligrams/liter)	Organic contaminants	Advisory level [a] (milligrams/liter)
Acenaphthene		2,4-Dichlorophenol [c]	0.02
Acrylonitrile [b, c]	0.00006 !	1,1-Dichloropropane	
Benz(a)anthracene	0.0001 !	1,3-Dichloropropane	
Benzo(b)fluoranthene	0.0002 !	2,2-Dichloropropane	
Benzo(k)fluoranthene	0.0002 !	1,1-Dichloropropene	
Bromobenzene		Diethyl phthalate [c]	5.0
Bromochloroacetonitrile		Dimethyl phthalate	
Bromodichloromethane [c, d]	0.0006 !	Fluorene	
Bromoform [c, d]	0.004 !	Fog oil	
n-Butylbenzene		Formaldehyde [c]	1.0 !
sec-Butylbenzene		Indeno (1,2,3,-c,d) pyrene	0.0004 !
tert-Butylbenzene		Isopropylbenzene	
Butyl benzyl phthalate	0.1	Methyl ethyl ketone	
Chloral hydrate [c, e]	0.06	Methyl tert butyl ether [c]	0.04
Chlorodibromomethane [c, d]	0.06	Monochloroacetic acid	
Chloroethane		Pentachloroethane	
Chloroform [c, d]	0.006 !	Phenanthrene	
2-Chlorophenol [c]	0.04	n-Propylbenzene	
Chloropicrin [b]		Pyrene	
Chrysene	0.0002 !	1,1,2,2-Tetrachloroethane	
Cyanogen chloride		Trichloroacetic acid [b, c, e]	0.3
p-Cymene		Trichloroacetonitrile	
Dibenz(a,h)anthracene	0.0003 !	2,2,2-Trichloroethanol	
Dibromoacetonitrile [c]	0.02	2,4,6-Trichlorophenol [b, c]	0.003 !
Dibromomethane		1,1,1-Trichloropropane	
Dibutyl phthalate		1,2,3-Trichloropropane	0.04
Dichloroacetaldehyde		1,1,2-Trichloro-1,2,2-trifluoroethane	
Dichloroacetic acid [e]	0.06 !	1,2,4-Trimethylbenzene	
Dichloroacetonitrile [c]	0.006	1,3,5-Trimethylbenzene	
1,1-Dichloroethane			

See footnotes on page 87.

Table A.3
Additional U.S. EPA drinking water contaminants for which documentation is unavailable (as of May 1994)—*continued*

Inorganic contaminants	Advisory level [a] (milligrams/liter)	Inorganic contaminants	Advisory level [a] (milligrams/liter)
Aluminum [b]		Chlorite [c]	0.08
Bromate	0.01	Hypochlorite	
Chloramine [c]	3.0/4.0	Molybdenum [b, c]	0.04
Chlorate [b]		Sodium	
Chlorine	4.0	Strontium [c]	17.0
Chlorine dioxide [c]	0.3	Vanadium	

Source: Drinking Water Regulations and Health Advisories. Office of Water, U.S. Environmental Protection Agency, Washington, D.C. (May 1994).

[a] The listed advisory levels are Lifetime Health Advisory Levels, tentative Maximum Contaminant Levels (MCLs), or proposed MCLs. Water with a contaminant concentration at or below the advisory level is acceptable for drinking every day over a lifetime and does not pose any health concerns unless the advisory level is marked with a "**!**". For these contaminants, the U.S. Environmental Protection Agency assumes that there is no risk-free dose, as the contaminant is a known or probable carcinogen. Daily consumption of water with a carcinogenic contaminant concentration equal to the advisory level will theoretically result in a one-in-a-million chance of developing cancer as a direct result of ingesting the contaminant.

[b] This contaminant is an ingredient in some pesticide products and therefore may be distributed under several different product names. See appendix C, table C.1, for a list of product names.

[c] The advisory level listed for this contaminant is from a draft health advisory.

[d] This contaminant is a trihalomethane (THM). The U.S. Environmental Protection Agency has stated that the total Maximum Contaminant Level for all THMs combined cannot exceed 0.80 milligram per liter.

[e] This contaminant is a haloacetic acid. The U.S. Environmental Protection Agency has stated that the total Maximum Contaminant Level for all haloacetic acids combined cannot exceed 0.06 milligram per liter.

[!] See footnote "a."

Appendix B

U.S. EPA Secondary Drinking Water Standards

Table B.1
U.S. EPA Secondary Drinking Water Standards (as of May 1994)

Contaminant	Uses and/or sources	Possible water quality effects	Possible water treatment methods [a]	Secondary Maximum Contaminant Level (SMCL)
Aluminum [b, c]	Occurs naturally in most foods; may be added during municipal water treatment	Posttreatment precipitation in municipal drinking water systems	• Distillation • Reverse osmosis • Ozonation	0.05 to 0.2 milligram/liter
Chloride	Found in natural minerals, sea water, road salt, fertilizers, industrial wastes, and sewage	Salty taste; corroded pipes, fixtures, and appliances; blackening and pitting of stainless steel	• Distillation • Reverse osmosis	250 milligrams/liter
Color	Results from iron, copper, or manganese; organic chemicals; and decaying organic matter	Visible tint	• Activated carbon • Ozonation • Precoat filter containing activated carbon • Multimedia filter containing activated carbon	15 color units
Copper [b, c]	Leaches from copper and brass water pipes and tubing; found in industrial and mining wastes and copper salts used to control algae in municipal water treatment	Bitter or metallic taste, blue-green stains on plumbing fixtures	• pH adjustment to prevent corrosion of the water distribution system • Distillation • Reverse osmosis	1.0 milligram/liter
Corrosivity	Depends on temperature, acidity, hardness, and oxygen content of water	Corrosion of household plumbing; corrosion products may cause health effects, metallic taste, or staining; corrosion products may include lead, copper, iron, or zinc	• pH adjustment to prevent corrosion of the water distribution system	Noncorrosive

See footnotes on page 90.

Table B.1
U.S. EPA Secondary Drinking Water Standards (as of May 1994)—*continued*

Contaminant	Uses and/or sources	Possible water quality effects	Possible water treatment methods [a]	Secondary Maximum Contaminant Level (SMCL)
Fluoride [c, d]	Found in natural minerals and industrial wastes	Brownish discoloration of teeth	• Activated alumina • Reverse osmosis • Distillation • Anion exchange	2.0 milligrams/liter
Foaming agents	Found in household and industrial wastes	Frothy, cloudy appearance; soapy taste; unpleasant odor		0.5 milligram/liter
Iron	Found in natural deposits in rocks and soil; results from corrosion of iron pipes and fixtures in water distribution systems	Rusty sediment; bitter, metallic taste; brown-orange stains on fixtures; iron bacteria; discolored beverages	• Water softener (0.3 to 3.0 milligrams/liter) • Phosphates (0.3 to 3.0 milligrams/liter) • Oxidizing filter (3.0 to 10.0 milligrams/liter) • Chlorination followed by filtration (greater than 10.0 milligrams/liter) • Oxidation with potassium permanganate • Ozonation	0.3 milligram/liter
Manganese	Found in natural deposits in rocks and soil	Brownish color; black stains on laundry and fixtures; bitter, metallic taste; altered taste of water-mixed beverages; black sediment	• Chlorination followed by filtration • Oxidizing filter • Ozonation • Water softener • Oxidation with potassium permanganate	0.05 milligram/liter
Odor	Results from dissolved gases, minerals, and chemicals; leaking underground storage tanks; landfill or septic runoff; and organic matter	"Rotten egg," septic, musty, or chemical smell	• Activated carbon • Ozonation • Precoat filter containing activated carbon • Multimedia filter containing activated carbon	3 threshold odor numbers

See footnotes on page 90.

Table B.1
U.S. EPA Secondary Drinking Water Standards (as of May 1994)—*continued*

Contaminant	Uses and/or sources	Possible water quality effects	Possible water treatment methods [a]	Secondary Maximum Contaminant Level (SMCL)
pH	Results from dissolved acid and alkaline materials	Pitting of pipes and fixtures, bitter or metallic taste (low pH), slippery feel, soda taste, scaly deposits (high pH)	• Neutralizing filter (pH 5.5 to 6.5 only) • Soda ash injection (pH less than 6.5) • Acid injection	6.5 to 8.5
Silver [c]	Trace amounts in water result from natural sources and industrial wastes	Argyria—a blue-gray discoloration of the skin and organs	• Distillation • Reverse osmosis • Ozonation	0.1 milligram/liter
Sulfate	Found in natural deposits or salts, byproducts of coal mining, industrial wastes and sewage, and streams draining coal or metal-sulfide mines	Bitter, medicinal taste; scaly deposits; laxative effects; "rotten egg" odor from hydrogen sulfide gas formation	• Distillation • Reverse osmosis • Anion exchange	250 milligrams/liter
Total dissolved solids (TDS)	May result from carbonates, bicarbonates, chlorides, sulfates, phosphates, nitrates, calcium, magnesium, sodium, potassium, iron, manganese, or other constituents	Hardness; scaly deposits; sediment; cloudy, discolored water; odor; staining; salty or bitter taste	• Distillation • Reverse osmosis	500 milligrams/liter
Zinc [b, c]	Found in natural deposits; results from leaching of galvanized pipes and fittings	Metallic taste	• Distillation • Reverse osmosis • pH adjustment to prevent corrosion of the water distribution system • Ozonation	5.0 milligrams/liter

Source: Secondary Maximum Contaminant Levels (SMCLs) are taken from *Drinking Water Regulations and Health Advisories,* Office of Water, U.S. Environmental Protection Agency (EPA), Washington, D.C. (May 1994). Uses and/or sources (except those marked with an asterisk), possible water quality effects, and possible water treatment methods all excerpted from various health advisories published on various dates by the EPA Office of Water. Uses and/or sources marked with an asterisk excerpted with permission from the *1994 Farm Chemicals Handbook,* Meister Publishing Company.

[a] The water treatment recommendations in this table are general. The water pH, total dissolved solids (TDS), other dissolved or particulate substances, or other water quality or water distribution system factors may affect the effectiveness of a treatment device. Be sure to investigate the limitations of a device before purchasing.

[b] This contaminant is an ingredient in some pesticide products and therefore may be distributed under several different product names. See appendix C, table C.1, for a list of product names.

[c] See also appendix A.

[d] Fluoride concentrations in the range of 1.0 milligram per liter are desirable in drinking water for protection against tooth decay. For this reason, fluoride may be added to a municipal water supply. The actual optimum concentration is based on average daily air temperatures at the location. See also appendix A, table A.1.

Appendix C

Pesticide Products That Contain U.S. EPA Drinking Water Contaminants

Table C.1
Pesticide products that contain U.S. EPA drinking water contaminants

Possible drinking water contaminant	Selected pesticide products that contain the contaminant
Acifluorfen	Blazer, Doble, Galaxy, Galaxy Top, Scepter O.T., Storm, Tackle†
Acrylonitrile	Acritet†, Acrylofume†, Acrylon†
Alachlor	Alagan, Alanex, Alanox, Alatox†, Alazine, Bullet, Cannon†, Chimichlor, Crop Star, Freedom, Lariat, Lasso, Lazo, Micro-Tech, Nudor Extra, Partner, Pillarzo, Ralchlor, Rastra, Satochlor
Aldicarb	Sanacarb, Temik
Aldicarb sulfone	Standak
Aldrin	Aldrite†, Altox†, Seedrin Liquid†
Aluminum	Agtoxin, Alphos, Celphide, Celphine, Celphos, Degesch Phostoxin, Delicia†, Delicia Gastoxin†, Fertoxin BR, Fumitoxin, Gastoxin, L'Fume, Quickphos, Quikfume, Sanifume
Ametryn	Ametrex, Ametrex Extra, Ametron, Bimetron, Crisazina-Crisatrina Kombi, Evik, Gesapax, Trinatox-D, X-sipax
Ammonium sulfamate	Amcide†, Ammate†, Ikurin†, Sulfamate†
Antimony	Brennotox, Tartox, Thriptox
Arsenic	Ansar 6.6, Ansar 8100, Arrhenal, Arsinyl, Arsonate Liquid, Atlas "A"†, Bolate, Bolls-Eye†, Bophy, Broadside†, Bueno 6, Cacodylate, Check-Mate†, Chem Pels C, Chem-Sen 56, Chip-Cal†, Chipco Crab Kleen†, Clean-Boll†, Cotton Aide HC, Crab-E-Rad†, Croak†, Daconate 6, Daconate Super, Dal-E-Rad, Dilic†, Dinate†, Di-Tac, Diumate, DMA, DMA 100, Drexar 530, Drexel MSMA, DSMA 63P, DSMA 81P, DSMA Liquid, DSMA Slurry, Dutch Treat†, Ezy Pickin'†, Gypsine, Herb-All, Hi-Yield Desiccant H-10, Kack†, Kill-All, Leaf-All, MAMA, Merge 823, Mesamate, Methar 30, Moncide, Monex 3†, Montar, Namate†, Pencal†, Penite, Phyban H.C.†, Phytar, Phytar 138†, Phytar 560†, Prodalumnol Double, Rad-E-Cate 25†, Silvisar 510†, Silvisar 550†, Sodar, Soprabel, Spra-Cal, Super Arsonate, Talbot†, Target MSMA 4, Trans-Vert†, Trimec Plus, Turf-Cal FL, Vegabate I†, Weed Broom†, Weed-E-Rad 360†, Weed-Hoe, Zotox Crab Grass Killer

† Discontinued

Table C.1
Pesticide products that contain U.S. EPA drinking water contaminants—*continued*

Possible drinking water contaminant	Selected pesticide products that contain the contaminant
Atrazine	AAtrex, Aktikon†, Alazine, Aneldazin, Atra-Bor†, Atramet Combi, Atranex, Atranex Combi, Atrataf, Atratol 8P†, Atratol 90†, Atred†, Azinotox-500, Bicep, Bullet, Candex, Conquest†, Crisazina, Crisazina-Crisatrina Kombi, Drexel Atrazine, Erunit, Extrazine†, Extrazine II, Farmco Amizine–AA Flowable, Farmco Atrazine, Flotrazine, Gesaprim, Griffex†, Laddok, Malermais, Maxipack Trac 50, Prado, Primatol A, Primextra, Prompt, Prozine†, Rack Granular†, Rastra, Rhino, Sanazine, Simazat, Sutazine, Tomahawk, Trac 50, Vegfru Solaro, Weed Pro, X-siprim, Zeapos
Barium	Coccins, Solabar, Solbar, Zolfosol
Baygon	Blattanex, Bripoxur, Mitoxur, Pillargon, Prentox Carbamate, Propogon†, Propoxan, Proprotox, Propyon, Prox, Suncide, Tugen, Unden
Bentazon	Acumen, Aramo, Basagran, Basagran KV, Basagran KV-P, Basagran M, Basagran M60, Basagran M75, Basagran PL2, Basagran Ultra, Bentazon 60, Campogran, Diamant, Doble, Entry, Extoll, Galaxy, Grasszin, Laddock, Leader, Pledge†, Prompt, Pulsar, Storm, Triagran, Ultima Plus, Vega Plus, Wider
Benzene	Benzol†
Boron	Pyrobor†, Three Elephant†, Tronabar†, V-Bor†
Bromacil	Borea†, Bromax†, Chlorvar†, Cynogan†, Dakar, Hibor C†, Hyvar, Krovar, Steriweed†, Uradex†, Uragan, Urox "B", Urox HX†, Weed Broom†
Bromomethane	Bromocoop, Celfume, Drexel Plant Bed Gas†, Kayafume, MeBr, Mebrom†, Meth-O-Gas, Terr-O-Cide II, Terr-O-Gas, Terr-O-Gel†
Butylate	Anelda Plus, Aneldazin, Anelirox, Genate Plus, Rhino, Sutan +, Sutazine, Tomahawk
Cadmium	Caddy†, Cadminate†, Cad-Trete†, Crag Turf Fungicide 531, Kromad†, Mer-Cad†, Miller 531†
Carbaryl	Adios, Bug Master, Carbamine, Cekubaryl, Crunch, Denapon, Devicarb, Dicarbam†, Drexel Carbaryl, Hexavin, Karbaspray, Kilex Carbaryl, Nac, Ravyon†, Savit†, Sedit F 935, Septene, Sevidol, Sevimol, Sevin, Sevin 5 Bait, Sevin 5 Dust, Sevin 10 Dust, Slam, Sulfaril, Tercyl, Tricarnam, Vanisect
Carbofuran	Carbodan, Chinufur†, Curaterr, Furacarb, Furadan, Furasul, Futura, Pillarfuran, Sunfuran, Vegfru Diafuran, Yaltox
Carbon tetrachloride	Acrylon†
Carboxin	Abavit/Prelude Universal, Beret Universal, Enhance, Enhance +, Flo Pro V†, Germate Plus, Kemikar, Kisvax, Oxatin, Prevail, Pro-Gro, RTU-Vitavax-Thiram, Seed Shield Vitavax Captan 20-20, Vitavax, Vitavax 30 C, Vitavax 34, Vitavax-200, Vitavax-PCNB
Chloramben	Amiben, Amilon WP†, Dynocam†, Ornamental Weeder 4G†, Vegiben†

† Discontinued

Table C.1
Pesticide products that contain U.S. EPA drinking water contaminants—*continued*

Possible drinking water contaminant	Selected pesticide products that contain the contaminant
Chlorate	Atlacide†, Atratol 8P†, BareSpot Ureabor, BareSpot Weed and Grass Killer, Chem-Frost†, Chloracil, Chlorax†, Chlorea†, Chlorvar†, Defoal, Defol 6†, De-Fol-Ate, Dervan, Desecol, Drop-Leaf, E-Z-Off, Fall, Harvest Aid Liquid, Hibor C†, Klorex†, KM, Kusatol, Leafex, Magron, MBC†, MC Defoliant, Ortho MC, Oxycil†, Oxy Leafex-3†, Polybor-Chlorate†, Rasikal†, Shed-A-Leaf†, Tumbleleaf†, ValDrop†
Chlordane	Aspon-chlordane†, Belt†, Chlordrite, Chlor Kil†, Chlortox, Corodane†, Gold Crest C-100†, Kilex Chlordane†, Kypchlor†, Mahatz, Niran†, Octachlor†, Octa-Klor†, Ortho-Klor†, Synklor†, Termex, Termidan, Termide, Termi-Ded†, Termiseal, Topiclor 20†, Velsicol 1068†
Chloropicrin	Acquinite, Bromocoop, Brom-O-Gas, Brom-O-Sol, Chlor-O-Pic, Dojyopicrin, Dolochlor, Drexel Plant Bed Gas†, Larvacide, Pic-Clor, Picfume†, Picfume A†, Profume A, Rootect Oil, Terr-O-Gas, Terr-O-Gel†, Tri-clor
Chlorothalonil	Arpege EPI, Bravo, Bravocarb, Bravo C/M, Bravonil, Bravo S, Bravo Zn, Chlorosul, Clorto Caffaro, Clortocaf Ramato, Clortosip, Colonil, Corbel CL, Corbel Star, Corbel Triple, Dacobre, Daconil 2787, Echo, Eminent Star, Exotherm Termil, Funconil, Impact, Pillarich, Planete, Ridomil/Bravo, Rothalonil, Taloberg, Trimedac, Tuff Brite, Tuffcide
Chlorpyrifos	Brodan, Chlorofet, Contra-Insect, Deviban, Dorsan, Dowco 179†, Dowco 214†, Dursban, Empire, Equity, Eradex, Genpest, Lentrek, Lock-On, Lorsban, Lorsban 30, Lorsban 50-SL, Pageant, Piridane, Pyriban, Pyrinex, Reldan 3% Dust, Reldan 4E, Salut, Saluthion, Stipend†, Sulban, Thi Lor, Tricel
Chromium	Celcure, Chapco CCA-C 50†, Miller 658†, Mitrol CCA†, Woodguard CCA-50†
Copper	Agroram, Air-Flo Green, Algae-Rhap CU 7, Algaetrol 76†, Algimycin PLL-C, Aviocaffaro, Aviso Cup, BASF Grunkupfer†, Basic Copper 53, Basicop, Bioquin, Blitox, Blue Diamond, Blue Shield, Blue Viking, Bordocop, Caocobre, Carbocop, Celcure, Champ, Champion, Champion 20/20, Chapco Cu-Nap 8%†, Chempar, Cheshunt compound, Clortocaf Ramato, CNC, Cobox, COC, COCS, Colloidox†, Comac 23-35, Comac Parasol, Copac E, Cop-O-Cide†, Cop-O-Zinc 25-25, Coppercide 23, Coppercide 50, Copper-Count-N, Copperized Boliden Salts, Copper Nordox, Copper Power, Copper Pride, Copper S, Copper Sandoz, Copper Uversol, Coppo W, Coprantol, Copro, Coptox, Coxysan†, Coxysul, CP-TS 53, Criscobre, CS-56, Cudrox, Cuidrox, Cunapsol, Cunilate 2472, Cupox, Cupramar, Cuprantol, Cupravit, Cuprenox, Cuprinol, Cuprocaffaro, Cuprocop, Cuprokylt, Cupromin, Cuprosan, Cuprossina, Cuprovinol, Cuprox, Cuproxat, Cuproxat flüssig, Cuproxide, Curap 20, Devicopper, Dokirin, Fruitdo, Fungi-Rhap Cu-53†, Fungi-Rhap Cu-56†, Fungi-Rhap Cu-75†, Fytolan, Galben C 4-33, Galben R, Hidrocob, Hidroflow, Hydrocop, Hydrox, Idrorame FL, Kauritil†, Kilcop 53D†, Kilex, Kobasic†, Kocide, Kocide 20/20, Kocide 4045, KOP 300, KO-Zinc WP, Malachite, Manpower†, Miller 658†, Mitrol PQ†, Neoram, Neoram blu, Nordox, Nucop, Nutra-Spray†, Oleocuivre, Oleo Nordox, Oxycop, Oxycop 8L, Oxycop Dry S, Pasta Caffaro, Perm E-8, Phyto-Bordeaux, Phyton-27, PQ-8, Recop, Rhodiacuivre†, Ricetrine†, Seed Guard, Sulfacop, Sultricob, Super Cu, Sutricop†, Tairel R, TNCS 53, Triangle, Tri-Basic, Tricop, Troysan Copper 8%, Vacomil, Vacomil-Plus, Vencedor†, Viricuivre†, Vitigran†, Wiltz-65, Wittox C, Yellow Cuprocide

† Discontinued

Table C.1
Pesticide products that contain U.S. EPA drinking water contaminants—*continued*

Possible drinking water contaminant	Selected pesticide products that contain the contaminant
Cyanazine	Bladex, Conquest†, Extrazine†
Cyanide	A-Dust†, Cyanogas†, Cyanogas A, Cyanogas Fumigant†, Cymag, Degesch Calcium Cyanide A-Dust†, Degesch Calcium Cyanide G†
2,4-D	A-4D, Actril DS, Agrotect†, AGSCO 400, Amine 400 2,4-D Weedkiller, Aminol 806, Amoxane, Amsol, Aqua-Kleen, Barrage, BH 43†, Brush Killer 2D + 2DP, Chipco Turf Herbicide D†, Chipco Turf Kleen†, Chloroxone, Cornox, Crisalamina, Crisamina, Crop Rider, Curtail, D 50†, Dacamine, D-Amin, Debroussaillant 600, Ded-Weed†, Ded-Weed SULV, Desormone†, Dicotox†, Dikamin, Dikonirt, Dinoxol, Dissolve, DMA 4†, Dormone, DPC, Duplosan DP-D, Dymec, Emulsamine BK, Emulsamine E-3, Envert 171, Esterdefore, Esteron 99C, Fernesta†, Fernimine, Fernoxone, Formula 40, Grasszin D, Grazon P+D, Hedonal†, Herbalin SC, Herbanil 368, Herbi-D 480, Herbidal, Herbifen, Hi-Dep, Kaislantuho†, Knoxweed†, Lawn-Keep, Legumex Extra, Lentemul, Lontrel 205, LV 400 2,4-D Weedkiller, Macondray, Malerbane, Malerbane Cereali, MCPP-2,4-D, Mecopar†, Miracle, Navigate, Netagrone 600, Pathway, Pennamine D†, Phenaban 801†, Planotox, Plantguard, 2 Plus 2, Rodamine, Salvo, Sanaphen, Savage, Spritz-Hormin, Steriweed†, Superormone Concentre†, Super Trimec, Super Weedone, Tiller, Tordon 101 Mixture, Transamine†, Tributon, Trimec 992, Trimec Bentgrass, Trimec Brushmaster Brushkiller, Trimec Classic, Trimec Plus, Trimec Southern, Trinatox D, Trio, Triplet, U 46 Combi-Fluid, U46 D-Fluid, U 46 KV-Combi-Fluid, Vegemec, Vi Par†, Visko-Rhap†, Weed-Ag-Bar†, Weedar 64, Weedatul†, Weed-B-Gon, Weed Broom†, Weedez Wonder Bar†, Weedone, Weedone 170, Weed Pro, Weed Rhap, Weedtox, Weedtrol
Dacthal (DCPA)	Decimate
Dalapon	Basfapon†, Chloropon, Dalacide, Dalapon 85†, Dalapon-Na, Ded-Weed†, Devipon†, Dowpon M†, Gramevin, Kaislantuho†, Radapon†, Revenge, SLAM, Steriweed†, Target, Unipon
Diazinon	Adizon, Agrox 2-Way, Agrox 3-Way†, Agrox D-L Plus, Alfa-tox†, Basudin, Bean Seed Protectant†, D 264†, Dazzle†, Diagran, Dianon, DiaTerr-Fos, Diazajet, Diazatol, Diazide, Diazol, Dizinon, Drawizon, Dyzol, Fezudin†, Gardentox, Kayazinon, Kayazol, Neocidal, Nipsan, PT 265, Sarolex, Spec-tracide
Dibromochloropropane	BBC 12†, Fumazone†, Nemafume, Nemagon†, Nemanax, Nemaset, Nematocide†, Oxy DBCP†
Dicamba	Banlene Plus, Banlene Solo, Banvel, Banvel 720, Banvel SGF, Banweed†, Diamant, Docklene, Fallowmaster, Farmco One-Shot, Hormotuho Special†, Marksman, Metabane, Mondak, Trimec 992, Trimec Bentgrass, Trimec Brushmaster Brushkiller, Trimec Classic, Trimec Southern, Triplet, Tri-Power, Trooper†, Wallop, Weedmaster
p-Dichlorobenzene	Paracide, Paradow†, PDB, Santochlor†
1,3-Dichloropropene	Condor, D-D 92, Telone, Telone II, Telone C-17
Dieldrin	Alvit†, Dieldrex†, Dieldrite†, Octalox†, Panoram D-31

† Discontinued

Table C.1
Pesticide products that contain U.S. EPA drinking water contaminants—*continued*

Possible drinking water contaminant	Selected pesticide products that contain the contaminant
Dinoseb	Acricid†, Ambox†, Aretit†, Basanite†, Caldon†, Chemox†, Chemsect†, Dapacryl†, Dinitro†, Dinitro Weed Killer†, Dyanap†, Dynamyte†, Dynoram†, Elgetol 318†, Endosan†, Enide Dinitro†, Gebutox†, Hel-Fire†, Ivosit†, Kiloseb†, Klean Krop†, Morocide†, Morrocid†, Nitropone C†, Phenotan†, Premerge†, Premerge Plus†, Sinox General†, Subitex†, Unicrop DNBP†, Vertac†
Diphenamid	Dymid, Enide†, Enide Dinitro†, Rideon†, Trefmid†
Diphenylamine (DPA)	Big Dipper, Coraza, Deccoscald 282, No Scald DPA 283, Scaldip, Shield DPA
Diquat	Actor†, Aquacide, Diquat Herbicide, Herbaxon†, Pathclear, Preglone, Priglone, Reglone, Reglox, Reward, Weedol†, Weedtrine-D, Weedtrine-Plus†
Disulfoton	Disultex, DiSyston, Di-Syston, Dithiodemeton†, Dithiosystox†, Ekanon, Ethiometon, Frumin AL, Insyst-D†, Knave, Mocap Plus 4-2 EC, Solvirex
Diuron	Acert, Ametron SC, Bimetron, Cekiuron, Chlorea†, Crisuron, Dailon, Dakar, Dexuron, Dialam, Diater†, Di-on, Direx, Ditox-800, Diumate, Diurex, Diurol, Diuron Bayer, Diuron Fersol, Dynex†, Farmco Diuron, Fortex SC, Ginstar, Gramuron, Herbixol†, Herburon 500 BR, Karmex, Krater, Krovar, Lucenit, Monex 3†, Paracol, Seduron, Sup'r Flo Diuron†, Tartan, Topsite, Totacol, Toterbane 50F, Tropuron, Unidron, Uradex†, Ureabor 8D†, Urox D†, Ustinex, Vonduci, Vonduron
Endothall	Accelerate, Aquathol, Aquathol K, Des-I-Cate, Endothal, Endothal Weed Killer†, ETH, Herbicide 273, Hydout†, Hydrothol 191, Hydrothol Turf Herbicide, Niagrathal†
Endrin	Endrex†, Hexadrin
Ethylene dibromide	Bromofume†, Celmide†, Dibrome, Dowfume†, E-D-Bee†, Kop Fume†, Nephis†, Soilbrom†
Fenamiphos	Nemacur
Fluometuron	Cotoran, Cotoran Multi, Cottonex, Croak†, Flo-Met, Meturon
Fonofos	Capfos, Cudgel, Dyfonate, Edge, Tycap
Glyphosate	Athado Super, Erranca, Fallowmaster, Fosmazina, Glialka, Glifonox, Glifosato Estrella, Glisompa, Glitex, Glycel, Glyphogan, Glyphosate 48, Glyphosul, Glyphotox, Glytex, Ground-Up, Herbolex, Honcho†, Jury, Lider, Pillaround, Pin Up, Pondmaster, Rattler, Rodeo, Rondo, Rophosate, Roundup, Sunup, Tecoglif, Tomcato, Wallop, Weedoff
Heptachlor	Biarbinex, Cupincida, Drinox H-34 Heptamul, Fennotox, Gold Crest H-60†, Heptox, Termide, Vegfru Heptox
Hexachlorobenzene	Anticarie†, Ceku C.B.†, Granero†, No Bunt, Res-Q†
Hexazinone	Velpar, Velpar K
Lead	Gypsine, Soprabel, Talbot†

† Discontinued

Table C.1
Pesticide products that contain U.S. EPA drinking water contaminants—*continued*

Possible drinking water contaminant	Selected pesticide products that contain the contaminant
Lindane	Agronexit†, Agrox 3-Way†, Agrox D-L Plus, DB-Green, Enhance +, Etan 3G, Forlin, Gamaphex, Gamatin, Gammalin 20†, Gamma-Mean 400, Gamma-Mean L.O., Gamma-Mean Seed, Gammasan, Gamma-Up, Gammex, Geregam†, Germate Plus, Granol, Hammer, Inexit†, Isotox, Lacco Hi Lin†, Lacco Lin-O-Mulsion†, Lindagam, Lindane 30, Lindane 40%, Lindol 6G†, Lin-O-Sol†, Lintox, Nexit†, Noita-koisumu†, Novigam, Seed Shield Isopro, Seed Shield Maneb/Lindane, Seed Shield Protox, Sevidol, Silvanol, Sopragam†, Sulrenz, Vitavax
Malathion	Calmathion†, Capthion, Celthion, Cythion, Dielathion, Emmatos, Emmatos Extra, Exathion, For-Mal 50, Fyfanon, Hilmala, Hilthion, Karbofos, Khatau Malathion, Kop-Thion, Kypfos, Lucathion, Malamar, Malaphéle, Malaspray, Malathion 50, Malatol, Malatol Insecticide†, Malixol, Malmed, Maltox, OR-CAL Stabilized Malathion, Prentox Malathion 95% Spray, Rion, Sulmathion, Sumitox, Vap-Malathion, Vegfru Malatox, Zithiol
Maleic hydrazide	BH 43, Burtolin, Chemform, De-Cut, De-Sprout, Fair-2, Fair-30, Fair Plus, KMH, Maintain 3, Maleic Hydrazide 30%, MH 2P, MH 36 Bayer, Regulox 50W, Regulox W, Retard, Royal MH-30, Royal MH-30 SG, Royal Slo Gro, Sprout Stop, Stunt-Man, Sucker Atak, Sucker Stuff, Super De-Sprout, Super Hex, Super Sprout Stop, Super Sucker Stuff, Vonalhyde†, Vondrax
MCPA	Actril 3, Actril S, Acumen, Agroxone†, AGSCO MXL, Aramo, Banlene Plus, Basagran-M, BH MCPA, Bordermaster, Brominal Plus, Bronate, Butilglicolico, Cekherbex†, Cheyenne Herbicide, Chiptox, Curtail M, Dakota, Dakota TP, Ded-Weed†, Docklene, Duplosan DP-M, Duplosan Super, Empal, Farmco One-Shot, Gordon's Amine, Grasalam, Harness†, Hedonal M†, Hormotuho†, Hormotuho Special†, Kilsem, Legumex Extra, Lentemul, Malerbane MCPA, Matayuyos Selectivo MCPA, MCP, Mephanac, Rhomene, Rhonox, Sanaphen-M, Shamrox†, Superormone Concentre†, Tetroxone M†, Thomene, Tigrex, Tiller, Triagran, Triamine II, Triamine II W.S., Tri-Ester II, Trimec Encore, Tri-Power, Tropotox Plus, U 46 Combi-Fluid, U 46 DP-M-Fluid, U 46 M-Fluid, U 46 M-KV-Fluid, U 46 Super, Vacate†, Weedar, Weedone, Weed Rhap†, Zelan
Mercury	Agrox (phenylmercury urea)†, Ceresan L†, Chipcote†, Granosan†, Leytosan, Merbam 10†, Mer-Cad†, Mercan†, Mercaptide†, Mercuran†, Merfenel 51†, Mer Sol†, Merthon, Ortho LM Apple Spray†, Ortho LM Concentrate†, Ortho LM Seed Protectant†, Puratized B-Z, Quinex†, Setrete†
Methomyl	Agrinate, Kipsin, Kuik, Lannate, Lanox, Memilene L, Methavin, Methomex, Metofan, Metox-900, Nu-Bait II†, Nudrin†, Pillarmate, Stimukil
Methoxychlor	Alfa-tox†, Chemform†, Double-M, Double-M EC†, Flo Pro Mc†, Higalmetox†, Marlate, Moxie†, Prentox Methoxychlor†
Methyl parathion	A-Gro, Cekumethion, Devithion, Dimethyl Parathion, Dygun, Dypar, E 601, Ekatox, Folidol M, Fosferno M50†, Galecron†, Gearphos, Kilex Parathion, Mepaton, Meptox, Metacide, Metaphos, Methyl Fosferno, Metron†, Niletar, Nitrox 80†, Parapest M-50, Parasul, Parataf, Paraton, Paratox, Partron M, Penncap-M, Romethyl-P, Taxylone, Tekwaisa, Toll, Thylpar M-50, Unidol, Vegfru Klofos, Veto†, Wofatox

† Discontinued

Table C.1
Pesticide products that contain U.S. EPA drinking water contaminants—*continued*

Possible drinking water contaminant	Selected pesticide products that contain the contaminant
Metolachlor	Bicep, Broadstrike + Dual, Codal, Cotoran Multi, Cycle, Derby, Dual, Galex 500EC, Milocep†, Ontrack 8E†, Pennant, Primagram, Primextra, Pyracur, Turbo
Metribuzin	Lexone, Salute, Sencor, Sencoral, Sencorex, Turbo
Molybdenum	Agrosol, Agrosol Plus, Agrosol Pour-On, Captan Plus Molybdenum Flowable, Granox P-F-M
Naphthalene	Adrop Polvere, Amid-Thin, Celmone†, Fruit Fix, Fruit Fix 200, Fruit Fix 800, Fruite, Fruitone N, K-Salt Fruit Fix 200, K-Salt Fruit Fix 800, Liqui-Stik, NAA-800, Nafusaku, Olive Stop, Planofix†, Plucker†, Primacol, Rootone, Stik†, Stop-Sprout, Tekkam, Thin-it, Thin'n Stop-Drop, Tipoff†, Transplantone†, Trecit, Tre-Hold
Oxamyl	Pratt Oxamyl 10% G, Vydate L
Paraquat	Actor†, Cekuquat, Crisquat, Cyclone, Dextrone, Dexuron, Esgram†, Goldquat 276†, Gramocil, Gramonol, Gramoxone, Gramoxone Extra, Gramoxone S†, Gramuron, Herbaxon†, Herbikill, Herboxone, Osaquat Super, Paracol, Paquat, Pathclear, Pillarquat, Pillarxone, Preglone, Priglone, Starfire, Sweep†, Talent, Terraklene, Totacol, Total, Toxer, Weedol†
Pentachlorophenol	Antimicrobial†, Block Penta, Dowicide EC-7†, Dowicide G-ST†, Dow Pentachlorophenol DP-2†, GLAZD Penta, Mitrol G-ST, Napclor G†, Penchlorol, Pentacon, Penta EC-30†, Penta Plus 40, Penta Pres 1-10†, Penta Preservative Ready-to-Use P, Penta WR 1-5, Penwar, Permatox 101†, Permatox 181†, Permatox Penta, Pol-Nu, Priltox†, Santobrite†, Santobrite Beads†, Santobrite Fines†, Santophen†, Sinituho, Weedbeads†, Weedone†
Picloram	Access, Amdon†, Borolin†, Grazon, Grazon P + D, K-Pin†, Pathway, Pinene, Tordon, Tordon 101 Mixture
Prometon	Gesafram 50, Ontracic 800, Pramitol, Pramitol 5PS, Vegemec
Pronamide	Kerb
Propachlor	Bexton†, Niticid†, Ramrod, Satecid, Wallop G†
Propazine	Gesamil†, Milocep†, Miloguard†, Milo-Pro, Primatol P, Prozinex
Propham	Ban-Hoe†, Beet Kleen†, Birgin, Chem-Hoe†, Herald, Premalox†, Triherbide IPC, Tripece, Tuberite
Simazine	Amizine†, Aquazine†, Caliber 90, Cekusima, Derby, Drexel Simazine, Framed†, Genate Plus, Gesatop, Nezitec, Pathclear, Primatol S, Princep, Remtal SC, Simadex†, Simanex, Simazat, Simazina Atanor, Simazol, Tanzene†, Terraklene, Totazina
Styrene	Dowspray 9†
2,4,5-T	Brush Killer†, Brush-Rhap†, Brushtox†, Ded-Weed†, Esterone†, Farmco Fence Rider†, Forron†, Fruitone A†, Inverton 245†, Kaislantuho†, Line Rider†, Reddon†, Spontox†, Super D Weedone†, T-Nox†, Tormona†, Transamine†, Tributon†, Trinoxol†, Veon 245†, Verton 2T†

† Discontinued

Table C.1
Pesticide products that contain U.S. EPA drinking water contaminants—*continued*

Possible drinking water contaminant	Selected pesticide products that contain the contaminant
Tebuthiuron	Brush Bullet†, Graslan†, Perflan†, Spike
Terbacil	Geonter, Sinbar
Terbufos	Contraven, Counter, Counter CR, Pillarfox
Toxaphene	Camphoclor†, Camphofene Huileux†, Heliotox†, Motox†, Phenacide†, Phenatox†, Strobane T-90†, Toxakil†, Toxon 63†
2,4,5-TP	Amchem 2,4,5-TP†, Aqua Vex†, Ded-Weed†, Double Strength†, Fruitone T†, Kuron†, Kurosal†, Silvi-Rhap†, Weed-B-Gon†
Trichloroacetic acid	Dow Sodium TCA Inhibited, Dow Sodium TCA Solution, Konesta, NaTA, Varitox
1,1,1-Trichloroethane	Aerothene TT, Chlorothene Nu, Chlorothene SM
Trichlorophenol	Dowicide 2†, Dowicide 25†
Trifluralin	Acert, Ateflox, Broadstrike + Treflan, Buckle, Cannon†, 600-CE-Trifluralina, Commence, Digermin, Elancolan†, Flurene SE, Freedom, Herbiflan, Herbiflrin, Ipersan, Lance, Neminfest, Novolate, Olitreff, Pre-Empt†, Premerlin, Salute, Sinflouran, Snapshot 2.5TG, Super T, Su Seguro Carpidor†, Team, Terbalin, Trefanocide†, Treffer, Treficon†, Treflan, Trefmid†, Tretox 480, Tri-4, Trifluralina 600, Triflurex, Trifsan, Trilin, Trilin AT, Trim†, Tri-Scept, Triverdax
Zinc	Agzinphos, Antene†, Aspor, Billy†, Blue-Ox†, BSZ†, Carbazinc, Carbina TZ, Chem Zineb, Commando, Corozate, Cuman, Cumene†, Cuprosan, Cuprothex, Cupzin 60, Devizeb†, Dicamate, Dipher, Discon-Z, Dithane Z-78†, Ditiamino†, Fitodith 80, Flonex Z 400, Fuciram, Fuclasin Ultra, Fuklasin, Galben A†, Galben Z†, Golden Nutrient, Hexathane, Hexazir, Karamate, KO-Zinc WP, Kypzin, Lonacol†, Mancozan†, Mezene, Micosin F30, NU-Z, OR-CAL Ziram 400, Parzate C, Phosvin, Polyram Z†, Pomarsol Z Forte, Prodaram, Prozap, Ratol, Ridall-Zinc, Rodenticide AG Mole and Gopher Bait, Rodent Pellets, Sperlox†, Super Mixy, Tairel Z†, Tanazon†, Thionic, Tiazin†, Tiezene, Tricarbamix Z, Tricuproxi, Triscabol, Tritoftorol, Trizinoc†, Vancide MZ-96, Z-C Spray, Zebtox, Zerlate, Zidan†, Zincmate, Zinc Omadine, Zinc-Tox, Zinc Uversol Fungicide†, Zinesol, Zinosan†, Z.I.P.†, Ziram 4F, Ziram 76, Ziram 76WDG, Ziram Granuflo, Zirasan 90, Zirberk, Ziretec, Zirex 90, Ziride, Zitox, Zyban

Source: Excerpted with permission from the *1994 Farm Chemicals Handbook,* Meister Publishing Company.

† Discontinued

Appendix D
Conversion Factors

Table D.1
Conversion factors

To convert from	To	Multiply by
Area		
Square inch (in^2)	Square foot (ft^2)	6.944×10^{-3}
	Square centimeter (cm^2)	6.452
Square foot (ft^2)	Square inch (in^2)	144
	Square yard (yd^2)	0.1111
	Square mile (mi^2)	3.587×10^{-8}
	Acre	2.296×10^{-5}
	Square centimeter (cm^2)	929.0
	Square meter (m^2)	0.0929
Concentration		
Milligram per liter (mg/L)	Part per million (ppm)	1
	Grain per gallon (gpg or grain/gal)	0.05842
Grain per gallon (gpg or grain/gal)	Milligram per liter (mg/L)	17.17
Flow Rate		
Gallon per minute (gpm or gal/min)	Gallon per day (gpd or gal/day)	1,440
	Cubic foot per second (ft^3/sec)	2.23×10^{-3}
	Cubic foot per hour (ft^3/hr)	8.021
	Cubic meter per hour (m^3/hr)	0.2271
	Cubic meter per day (m^3/day)	5.42
	Acre-foot per day (AF/day)	4.42×10^{-3}
	Liter per second (L/sec)	0.06309

Table D.1
Conversion factors—*continued*

To convert from	To	Multiply by
Length		
Inch (in)	Foot (ft)	0.08333
	Yard (yd)	0.0278
	Millimeter (mm)	25.4
	Centimeter (cm)	2.54
Foot (ft)	Inch (in)	12
	Yard (yd)	0.3333
	Mile (mi)	1.89×10^{-4}
	Meter (m)	0.3048
	Kilometer (km)	3.048×10^{-4}
Micron	Micrometer (μm)	1
	Millimeter (mm)	0.001
	Inch (in)	3.937×10^{-5}
Nanometer (nm)	Angstrom (Å)	10
	Micron	0.001
Power		
Watt (W)	Horsepower (hp)	1.341×10^{-3}
	Foot-pound per second (ft-lb/sec)	0.7376
	Foot-pound per minute (ft-lb/min)	44.25
	Kilogram-meter per second (kg-m/sec)	0.1020
Pressure		
Pound per square inch (psi or lb/in^2)	Pound per square foot (lb/ft^2)	144
	Kilogram per square centimeter (kg/cm^2)	0.07031
	Foot of water (ft H_2O)	2.309
	Meter of water (m H_2O)	0.7031
	Inch of mercury (in Hg)	2.036
	Millimeter of mercury (mm Hg)	51.72
	Atmosphere (atm)	0.06805
Volume		
Gallon (gal)	Cubic inch (in^3)	231
	Cubic foot (ft^3)	0.1337
	Cubic yard (yd^3)	4.951×10^{-3}
	Cubic centimeter (cm^3)	3785
	Cubic meter (m^3)	3.785×10^{-3}
	Liter (L)	3.785

Table D.1
Conversion factors—*continued*

To convert from	To	Multiply by
Volume (continued)		
Quart (qt)	Cubic inch (in^3)	57.75
	Cubic foot (ft^3)	0.03342
	Cubic centimeter (cm^3)	946.4
	Ounce (oz)	32
	Pint (pt)	2
	Gallon (gal)	0.25
	Liter (L)	0.946
Cubic foot (ft^3)	Cubic inch (in^3)	1,728
	Cubic yard (yd^3)	0.03704
	Cubic centimeter (cm^3)	28,317
	Cubic meter (m^3)	0.02832
	Acre-foot (AF)	2.30×10^{-5}
	Gallon (gal)	7.48
	Liter (L)	28.32
Cubic meter (m^3)	Cubic inch (in^3)	61,024
	Cubic foot (ft^3)	35.32
	Cubic yard (yd^3)	1.308
	Cubic centimeter (cm^3)	1×10^6
	Gallon (gal)	264.2
	Liter (L)	1,000
Weight		
Grain (gr)	Ounce (oz)	2.286×10^{-3}
	Pound (lb)	1.429×10^{-4}
	Milligram (mg)	64.80
Ounce (oz)	Grain (gr)	437.5
	Pound (lb)	0.0625
	Gram (g)	28.35
Pound (lb)	Grain (gr)	7,000
	Ounce (oz)	16
	Gram (g)	453.6
	Kilogram (kg)	0.4536
Milligram (mg)	Grain (gr)	0.01543
	Ounce (oz)	3.527×10^{-5}
	Pound (lb)	2.205×10^{-6}
Gram (g)	Grain (gr)	15.43
	Ounce (oz)	0.03527
	Pound (lb)	2.205×10^{-3}

Table D.2
Temperature conversions

To convert from degrees Fahrenheit (˚F) to degrees Celsius (˚C):

$$^{\circ}C = (^{\circ}F - 32) \div 1.8$$

To convert from degrees Celsius (˚C) to degrees Fahrenheit (˚F):

$$^{\circ}F = {}^{\circ}C\ (1.8) + 32$$

Table D.3
Metric (SI) prefixes and their corresponding multiplication factors

Prefix	Symbol	Multiplication factor
exa	E	10^{18} = 1,000,000,000,000,000,000
peta	P	10^{15} = 1,000,000,000,000,000
tera	T	10^{12} = 1,000,000,000,000
giga	G	10^{9} = 1,000,000,000
mega	M	10^{6} = 1,000,000
kilo	k	10^{3} = 1,000
hecto	h	10^{2} = 100
deka	da	10^{1} = 10
deci	d	10^{-1} = 0.1
centi	c	10^{-2} = 0.01
milli	m	10^{-3} = 0.001
micro	μ	10^{-6} = 0.000001
nano	n	10^{-9} = 0.000000001
pico	p	10^{-12} = 0.000000000001
femto	f	10^{-15} = 0.000000000000001
atto	a	10^{-18} = 0.000000000000000001

Glossary

A

Absorption. The process by which one substance is taken into the body of another substance, as when a sponge absorbs water. See also **adsorption**.

Acidity. A water quality parameter in which the pH is less than 7. See also **pH.**

Action level. The concentration of lead or copper in water specified by the U.S. Environmental Protection Agency as being acceptable for long-term consumption. The action level for copper is 1.3 milligrams per liter. The level for lead is 0.015 milligram per liter. If concentrations in municipal water systems exceed the action level, municipal treatment facilities must alter their treatment systems until copper and lead concentrations fall below these levels.

Activated alumina. An adsorption medium that reduces the concentration of fluoride, arsenic, selenium, and chromium. Activated alumina is formed when aluminum hydroxide is dehydrated at a temperature between 550 and 1,100 degrees Fahrenheit, then ground and screened. See also **adsorption**.

Activated carbon. An adsorption medium that reduces the concentration of some organic chemicals, radon, odors, tastes, and smells. It is formed when petroleum coke, bituminous coal, lignite, or wood products are crushed and heated to between 500 and 1,800 degrees Fahrenheit in the absence of air. The heat creates a porous structure that increases the surface area for adsorption. See also **adsorption**.

Adsorbent. During adsorption, the medium (usually a solid) to which a substance adheres. See also **adsorption**.

Adsorption. The process by which one substance adheres to the surface of another substance, usually a solid. See also **absorption** and **adsorbent**.

Aeration. A water treatment process that brings air into intimate contact with water, usually by spraying water into air or by bubbling air through water. Aeration increases the rate at which volatile organic chemicals (VOCs), radon, and other dissolved gases move from water to air.

Aesthetic. Referring to water characteristics such as taste, odor, color, and appearance that reduce the quality of drinking water but do not necessarily result in adverse health effects.

Algal bloom. A mass of algae that appears in lakes or ponds when the water has sufficient concentrations of nitrogen and phosphorus. Algal blooms give water a green, yellow, or brown color and often result in a depletion of dissolved oxygen in the water.

Alkalinity. A water quality parameter in which the pH is higher than 7. See also **pH**.

Anion. A negatively charged ion such as chloride (Cl^-), fluoride (F^-), or nitrate (NO_3^-). See also **cation**.

Anion exchange. A water treatment process in which objectionable anions such as nitrate are removed from water and replaced with less objectionable anions such as chloride. See also **cation exchange**.

Aquifer. A water-saturated geologic zone that yields a sufficiently high volume of water to supply wells and springs at a rate so that they can serve as practical sources of drinking water.

B

Backflow. An event that occurs when a potable water line is connected to a sewer line and pressure in the water line is lower than the pressure in the sewer line. The condition results in sewage flowing into the water line.

Back pressure. The pressure that builds on the treated water side of a reverse osmosis membrane as the treated water storage tank fills. See also **reverse osmosis**.

Backwash. To subject a filter bed to water flow in a direction opposite to the service flow. Backwashing loosens the filter bed and flushes solid materials that have accumulated in the bed to waste. A special solution is sometimes used to also regenerate the filter medium. See also **regeneration**.

Bacteria. Typically, one-celled microorganisms that have no chlorophyll and multiply by simple division. Some bacteria cause disease, but others are necessary for processes such as fermentation and nitrogen fixation. Bacteria range in diameter from 0.5 to 5.0 microns.

Base. A substance that releases hydroxide (OH^-) ions when dissolved in water, thus increasing the pH. A strong base will release a large number of hydroxide ions, whereas a weak base will release a small number of hydroxide ions. See also **pH**.

Birm. A manufactured oxidizing medium made of a light silicon dioxide with a manganese dioxide coating. Birm is used to reduce the concentrations of iron and manganese in water.

Blue Baby Syndrome. See **methemoglobinemia**.

Body feeding. Extending the filter run of a precoat filter by introducing doses of filter aid to water entering the device. See also **filter aid** and **precoat filter**.

Biofouling. The colonization of a treatment device or water distribution system by microorganisms. Biofouling results in a film composed of bacteria, other microorganisms, and slimes produced by the microorganisms. Biofouling can result in malfunction or failure of a treatment device, odors, discolored water, and corrosion.

Breakthrough. During the service life of a treatment device, the point at which the contaminant concentration in treated water exceeds a safe or acceptable level.

Bypass saturator. A nonelectric device used to add a chemical solution to water. Untreated water is diverted through a bed of solid tablets such as phosphate tablets; the tablets dissolve and the resulting solution reenters the water line. Solution concentrations may fluctuate with water flow.

C

Capacity. The characteristic of a treatment device that describes its performance. The total capacity comprises the contaminant removal capacity and the flow rate capacity. The contaminant removal capacity refers to the percent reduction in contaminant concentration between untreated and treated water and the total amount of contaminant a device can remove before maintenance is required. The flow rate capacity refers to the rate of water flow through a device and is measured in gallons per minute or gallons per day.

Carcinogenic. Capable of causing cancer in humans and animals.

Cartridge sediment filter. A mechanical filter that uses a cartridge made of paper, cellulose, polypropylene sheets, cloth, ceramic, or string to separate particles from water. The replaceable cartridge is inserted in a housing that is usually plastic.

Cation. A positively charged ion such as calcium (Ca^{2+}), magnesium (Mg^{2+}), or sodium (Na^+). See also **anion**.

Cation exchange. A water treatment process in which objectionable cations such as calcium are replaced with less objectionable cations such as sodium. See also **anion exchange** and **softening**.

Channeling. An event that occurs when untreated water passes through a treatment device without contacting the filter material or resin.

Chemical feed pump (also called a chemical feeder). A mechanical device designed to introduce chemicals into a water system at a rate proportional to the water flow.

Chemical treatment. Treatment that inactivates, changes the chemical form of, or reduces the concentration of a drinking water contaminant by the addition of a solid, liquid, or gas.

Chlorination. In home water treatment, the use of a chlorine solution to oxidize contaminants or disinfect water. Municipal systems more commonly use chlorine gas, which is too dangerous for home use.

Chlorine. A widely used disinfectant and oxidizing agent available in gaseous, liquid, or solid form. The chemical symbol for chlorine is "Cl."

Chlorine demand. The amount of chlorine that can be consumed or "used up" by organic matter (such as plant material), microorganisms, iron, and other oxidizable substances in untreated water. The chlorine demand is calculated by subtracting the free chlorine residual from the amount of chlorine added to the untreated water. See also **free chlorine residual**.

Chlorine residual. See **free chlorine residual**.

Clay. A soil particle having a diameter between 0.2 and 2.0 microns.

Clear water. A term used to differentiate between water containing dissolved iron (clear water) and water containing oxidized, or particulate, iron.

Coliform bacteria. A generally harmless indicator organism that is carried in the intestinal tract of humans and warm-blooded animals. A positive total coliform water test indicates possible contamination of the water supply. Coliform bacteria is also found in decaying vegetation and soil. See also **fecal coliform**.

Concentration. The ratio of the amount of one substance in another substance. For example, in seawater, the concentration of chlorine is approximately 19,000 milligrams of chlorine per liter of water.

Contact time. The amount of time that water is in contact with a treatment medium or chemical.

Contaminant. Any undesirable physical, chemical, radiological, or microbio-

logical substance in water that may have an adverse health or aesthetic effect.

Contaminant removal capacity. The percent reduction in a contaminant between untreated and treated water as well as the total amount of contaminant a device can remove before servicing is needed.

Corona discharge unit. A high-energy electrical apparatus. In water treatment, air or oxygen is passed through a corona discharge unit to produce ozone.

Corrosion. The dissolving or wearing away of metals.

Cryptosporidiosis. An often severe diarrheal illness that is caused by the ingestion of the *Cryptosporidium parvum* oocyst. It is particularly dangerous to the elderly, children, acquired immune deficiency syndrome (AIDS) patients, or others with low immunity. See also ***Cryptosporidium parvum (C. parvum)***.

Cryptosporidium parvum (C. parvum). A parasitic protozoan. The environmentally persistent oocyst formed during one stage of the parasite's life cycle ranges in diameter from 4 to 6 microns and, when ingested, may cause cryptosporidiosis. *Cryptosporidium parvum* resists chlorine disinfection and must be removed from water via filtration methods, distillation, or boiling. See also **cryptosporidiosis** and **oocyst**.

Cyst. A dormant stage in the life cycle of some parasites in which a resistant shell is formed around the parasite.

D

Dechlorination. The removal of excess chlorine from a treated water supply, usually with activated carbon.

Desiccant. A drying agent. In home water treatment, desiccants are sometimes used to dry air prior to ozonation.

Diatomaceous earth. A powdery material composed of the skeletal remains of sea organisms called diatoms. Diatomaceous earth, mined from deposits on dry land, is a common filter aid in precoat filters. See also **filter aid**.

Disinfection. A process in which disease-producing bacteria and other microorganisms are killed or inactivated (prevented from reproducing). It may involve using chemicals such as chlorine or physical treatment methods such as distillation.

Dissolved solids. Substances dissolved in water, including both organic and inorganic matter. See also **total dissolved solids (TDS)**.

Distillation. A water treatment process in which water is boiled and the resulting steam is collected and cooled in a separate chamber. Distillation disinfects water, reduces the concentration of toxic metals, and removes some organic contaminants.

Distilled water. Water that has been purified via evaporation followed by condensation. Distilled water contains minute amounts of dissolved solids.

DPD (diethyl phenylene diamine) colorimetric test. A water test for detecting the presence of a free chlorine residual in water. The test involves adding diethyl phenylene diamine to water; a color change occurs when chlorine is present. See also **free chlorine residual**.

Dumping. See **unloading**.

E

Equilibrium. The state in which the action of multiple forces produces a steady balance, resulting in no change over time. When a chemical reaction can proceed in two directions, equilibrium is reached when the rate of reaction is equal for both directions.

Erosion chlorinator. A nonelectric chlorinating treatment device in which water passes over solid chlorine tablets and dissolves the tablets to supply a chlorine solution. A water meter controls the water flow.

F

Fecal coliform. Coliform bacteria found in human and animal waste. In general, they are not harmful to humans, but their presence may indicate contamination of a water supply with human or animal waste and disease-causing organisms. See also **coliform bacteria**.

Filox. A manufactured resin used in oxidizing filters.

Filter. *(verb)* To send water containing particles through a filter medium in order to separate contaminants from the water. *(noun)* A treatment device used to carry out the process of filtration. A filter consists of a filter medium and suitable hardware for positioning and supporting the filter medium in the path of the water. See also **filter medium**.

Filter aid. A filter medium used in precoat filters. Common filter aids are diatomaceous earth and perlite. See also **diatomaceous earth** and **precoat filter**.

Filter cake. A densely packed layer of filter medium and suspended solids that develops on the surface of a filter medium. See also **filter medium**.

Filter element. A rigid structure that supports the septum in a precoat filter. The filter element and septum together support the filter cake. See also **precoat filter** and **septum**.

Filter medium. Plural **filter media**. The permeable substance or material in a filtering device that separates contaminants from water.

Filtration. The process of separating contaminants from water by passing water through a porous medium. See also **filter**.

Flow rate capacity. The rate of water flow through a treatment device measured in either gallons per minute or gallons per day.

Fluoride. A general reference to compounds containing fluoride that may be added to municipal water supplies (at a concentration in the range of 1.0 milligram per liter) to reduce the incidence of tooth decay. Fluoride may also be naturally present in water. Long-term consumption of water with a fluoride concentration greater than 4.0 milligrams per liter may cause bone damage or mottling of teeth. Long-term consumption of fluoride concentrations greater than 2.0 milligrams per liter may discolor teeth. The symbol for fluoride is "F^-."

Free chlorine residual (also called chlorine residual or free chlorine). Chlorine that remains in water after the chlorine demand is satisfied. The presence of a residual indicates sufficient chlorine was added to disinfect the water. See also **chlorine demand**.

G

Giardia lamblia (G. lamblia). A parasitic protozoan. The cyst formed during one stage of the parasite's life cycle ranges in diameter from 7 to 10 microns and may cause giardiasis in humans. *Giardia lamblia* can be removed from water via filtration methods, distillation, boiling, and ozonation. See also **cyst** and **giardiasis**.

Giardiasis. A disease, often characterized by diarrhea, that is caused by the presence of *Giardia lamblia* cysts in the intestinal tract. See also ***Giardia lamblia (G. lamblia)***.

Grain. A unit of measure equal to 1.43 x 10^{-4} pound or 0.0648 gram.

Grains per gallon (gpg). The weight of a substance, in grains, in 1 gallon of water. Commonly, grains of minerals per gallon of water is used as a measure of hardness. One grain per gallon is equal to 17.1 milligrams per liter (mg/L).

H

Hardness. A water condition caused mainly by calcium and magnesium ions. Hardness prevents soap suds from forming and results in mineral deposits in water heaters and other appliances.

Hydrocarbon. A compound containing only carbon and hydrogen.

I

Initial flow rate. The flow rate through a device immediately following installation and before contaminants accumulate in the device. It is especially important for mechanical filters, as the flow rate diminishes as particles accumulate. See also **flow rate capacity**.

In-line. Describes a water treatment device that is installed in the water supply line and treats all water moving through the line. See also **line-bypass** and **off-line**.

Inorganic. Refers to naturally occurring or synthetic chemicals such as salts, metals, and minerals. Inorganics may or may not contain carbon.

Iodine. A solid black crystal that is dissolved for use as a chemical oxidant and disinfectant. Iodine disinfection is approved by the U.S. Environmental Protection Agency only for short-term or limited use. The symbol for iodine is "I."

Ion. An atom or molecule that has a positive or negative electric charge.

Ion exchange. A water treatment process in which certain unwanted ions in water are replaced with less objectionable ones. The efficiency of exchange depends on the concentration of ions in the water, the attraction between the ion exchange resin and the unwanted ions, and the contact time between untreated water and the resin. See also **anion exchange** and **cation exchange**.

Ion exchange capacity. The amount of ions that can be removed by a specific ion exchange resin.

Iron. A metallic element often found in water supplies that occurs in natural deposits in rocks and soil. Iron may be a component of pipes and fixtures in household water distribution systems and, when present, may leach into drinking water. Concentrations of iron greater than 0.3 milligram per liter may give water a bitter, metallic taste; cause brown-orange stains on fixtures and laundry; discolor beverages; and result in red-brown sediment in dispensed water. The chemical symbol for iron is "Fe."

Iron bacteria. Bacteria that use iron as a source of energy. Iron bacteria oxidize iron and form a slime that can accumulate in water systems and plug wells, water treatment devices, and water distribution lines. Their presence can also result in discolored, or "rusty," water.

L

Lead. A hazardous metal. Lead may be a component of pipes, fixtures, and solders in household plumbing systems. When present, it may leach from household plumbing into drinking water. It may also be present in old paint. The chemical symbol for lead is "Pb."

Leakage. An event that occurs when a water softener is not fully regenerated at the bottom of the resin column; the result is that contaminants are deposited in the treated water when the device resumes functioning. See also **regeneration** and **resin.**

Line-bypass. Describes a water treatment device that treats water diverted from the cold water line and supplies treated water through a separate treated water faucet. Such a device allows water to continue to flow through the water distribution system while the treatment device is being serviced. See also **in-line** and **off-line**.

Liter (L). A unit of metric measurement for volume; roughly equivalent to 1 quart or 0.25 gallon.

M

Maximum Contaminant Level (MCL). The maximum permissible concentration of a contaminant in municipally supplied drinking water as established by the U.S. Environmental Protection Agency Primary Drinking Water Standards. See also **primary drinking water standards**.

MCL. See **Maximum Contaminant Level (MCL)**.

Mechanical filtration. A water treatment process used primarily to remove sediment or iron, manganese, or sulfur particles. During mechanical filtration, water passes through a filter medium such as cloth or sand and particles become trapped either on the surface of or within the medium. Mechanical filtration devices include cartridge sediment filters, media filters, multimedia filters, and precoat filters.

Media filter. A mechanical filter that consists of a tank, a single filter medium, a support system, and an underdrain. Untreated water flows through the medium, which retains suspended solids that are too large to pass through the pore structure of the medium. See also **filter medium** and **mechanical filtration**.

Medium. See **filter medium**.

Methemoglobinemia (also called Blue Baby Syndrome). A serious condition affecting infants in which the oxygen-carrying capacity of hemoglobin is reduced as a result of a reaction with nitrite. Nitrite can be formed from nitrate by intestinal bacteria. Infant hemoglobin is replaced by adult hemoglobin, which is relatively immune to nitrite, by the age of six months.

Microbe. See **microorganism**.

Microbial. Relating to microorganisms.

Microbiologically unsafe water. Water that is known to contain disease-causing bacteria, viruses, or other microbiological agents; shows a positive test for an indicator organism (coliform bacteria); or has been determined to be unsafe by an appropriate health or regulatory agency.

Micrometer. See **micron**.

Micron (same as micrometer). A linear measure equal to 0.00003937 inch or one millionth of a meter. The symbol for micron is the Greek letter "μ" (pronounced *myoo*).

Microorganism (same as microbe). A simple organism with microscopic dimensions.

Milligrams per liter (mg/L). A unit of measure used to express concentration, usually in reference to a liquid. Milligrams per liter indicates the number of milligrams (thousandths of a gram) of a contaminant (lead, for example) in 1 liter of water. Milligrams per liter is equivalent to parts per million (ppm) when used with water quality parameters. See also **parts per million (ppm)**.

Molecule. The smallest part of a substance capable of independent existence while retaining all of the properties of the substance. Molecules may be one atom or more than one atom.

Multimedia filter. A mechanical filter that consists of a tank, several layers of different filter media, a support system, and an underdrain. Untreated water flows through the media layers; suspended solids are retained in the layers. See also **filter medium** and **mechanical filtration**.

N

Net available pressure. In reverse osmosis systems, the pressure available to push water across the membrane. The net available pressure is calculated by subtracting the osmotic pressure and the back pressure from the applied household water pressure. See also **back pressure** and **osmotic pressure**.

Neutralization. The addition of an acid to a base or a base to an acid to produce a neutral solution. (Generally, neutral solutions are considered to have a pH of 7.) See also **pH**.

Nitrate. A common component of fertilizers that readily moves through the soil to groundwater. Excessive concentrations (greater than 10 milligrams per liter) in drinking water may cause health problems in infants. The chemical symbol for nitrate is "NO_3^-." See also **methemoglobinemia**.

Nitrate dumping. An event that occurs when sulfate ions displace nitrate ions on an anion exchange resin. This may result in a nitrate concentration in treated water that is greater than that in untreated water. See also **preferential treatment**.

O

Off-line. Describes a treatment device that is not connected to the water distribution system. Untreated water is added to the device manually. A countertop distiller is an example. See also **in-line** and **line-bypass**.

Oocyst. One stage in the life cycle of a large class of parasites.

Osmosis. Diffusion of a solvent such as water through a semipermeable membrane; the membrane allows the solvent to pass but not most dissolved substances. See also **reverse osmosis (RO)**.

Osmotic pressure. When two solutions of differing concentrations are separated by a semipermeable membrane (one permeable to water but not most dissolved solids), the excess pressure applied to the higher-concentration side to prevent water from moving across the membrane. See also **osmosis** and **reverse osmosis (RO)**.

Oxidation. A chemical reaction in which an atom, ion, or molecule loses one or more electrons. In water treatment, oxidation is used to precipitate dissolved

iron, manganese, and hydrogen sulfide so that they can be removed via mechanical filtration. See also **precipitate**.

Oxidizing agent. Any chemical capable of oxidizing another substance. Oxygen, chlorine, and iodine are examples used in home water treatment. See also **oxidation**.

Ozone. An unstable form of oxygen that occurs naturally in the upper atmosphere and can be created by exposing air or pure oxygen to electricity or ultraviolet light. In water treatment, ozone is a powerful oxidant and disinfectant. The chemical symbol for ozone is "O_3."

P

Parts per million (ppm). A unit of measure used to indicate the concentration of chemicals or other substances. The following comparisons help put the unit in perspective: 1 part per million is roughly equal to one drop in 60 quarts of water or one second in twelve days. Parts per million is equal to milligrams per liter (mg/L) when used with water quality parameters. See also **milligrams per liter (mg/L)**.

Pathogen. A disease-causing microorganism.

PCB. See **polychlorinated biphenyl (PCB)**.

Peak demand. The flow rate necessary to meet the expected maximum water use rate in a household. For instance, the flow rate needed when the washing machine, shower, and kitchen faucet are in use simultaneously.

Pellet dropper. A type of chlorinating treatment device that is filled with solid pellets of chlorine. The device periodically deposits pellets directly into a well, where they dissolve and form a chlorine solution.

Percent recovery. A term used to describe the amount of water flowing into a reverse osmosis treatment device that ultimately exits the device as treated water. The percent recovery is calculated by dividing the volume of treated water by the volume of untreated water that entered the device and multiplying by one hundred. See also **reverse osmosis (RO)**.

Percent rejection. A term used to describe the amount of a specific contaminant or total dissolved solids that a reverse osmosis treatment device removes from water. The percent rejection is calculated by subtracting the concentration of the contaminant in the treated water from the concentration in the untreated water, dividing by the concentration in the untreated water, and multiplying by one hundred. See also **reverse osmosis (RO)**.

pH. A measure of the alkalinity or acidity of water. The pH scale ranges from 0 (extremely acidic) to 14 (extremely alkaline). A pH of 7 is neutral. The pH scale is a nonlinear scale such that pH 6 is ten times more acidic than pH 7, and pH 5 is one hundred times more acidic than pH 7. Technically, the pH defines the relative concentration of hydrogen ions and hydroxide ions; as pH increases, the concentration of hydroxide ions increases.

Phosphates. Compounds used to tie up, or render inactive, metals or minerals in water (for example, minerals that cause hardness). Phosphate use is banned in some states. The chemical symbol for phosphate is "PO_4^{3-}." See also **algal bloom**.

Physical treatment. A water treatment process that removes contaminants from water without the addition of chemicals.

Picocurie (pCi). A unit of measure used to express radioactivity.

POE. See **point-of-entry (POE)**.

Point-of-entry (POE). A term that describes a device that treats all water entering a household.

Point-of-use (POU). A term that describes a device that treats water at a single tap or multiple taps but not water for the entire household. Point-of-use devices are generally used to treat water used only for cooking and drinking.

Polychlorinated biphenyl (PCB). A hazardous environmental pollutant that has various industrial applications and tends to accumulate in animal tissues.

Pore size. In mechanical filtration systems, the space between media granules or fibers. The pore size determines what size particles a filter can retain and varies around an average value that depends on how the filter was manufactured.

Posttreatment. Installing a device after the primary treatment device in a water treatment system. An example of posttreatment is removing any lingering chlorine taste or smell after chlorination. See also **pretreatment**.

Potable. Describes water suitable for human consumption.

Potassium permanganate. A dry, purplish solid used as an oxidizing agent in water treatment. The chemical symbol for potassium permanganate is "$KMnO_4$." See also **oxidation**.

POU. See **point-of-use (POU)**.

Precipitate. *(verb)* The formation of a solid from a solution. *(noun)* A solid that has formed from a solution.

Precoat filter. A mechanical filter that consists of a filter tank, powdered filter aid, and a porous membrane called the septum. Untreated water mixes with the filter aid and forms a filter cake that coats the septum. The filter cake traps suspended solids. See also **filter aid** and **septum**.

Preferential treatment. An event that occurs when untreated water contains several contaminants that are removable by a treatment device, but the device prefers one over another. For example,

an anion exchange unit prefers sulfate ions over nitrate ions, so sulfate ions are removed more readily when both ions are present in untreated water.

Pressure drop. The difference in water pressure that occurs between the inlet and outlet sides of a treatment device or between the outlet of a treatment device and a faucet in the home. Excessive pressure drop causes decreased water flow at faucets.

Pressure filter. A filter such as a cartridge sediment filter or media filter that is installed in a pressurized home water distribution system. A pour-through countertop filter is not a pressure filter.

Pretreatment. Installing a device before the primary treatment device to remove contaminants that might reduce the effectiveness or service life of the primary device. Pretreatment may include removing suspended solids that could shield microorganisms from disinfection.

Primary drinking water standards. Drinking water standards set by the U.S. Environmental Protection Agency (EPA) for municipal water treatment facilities to regulate levels of drinking water contaminants that affect human health. See also **secondary drinking water standards**.

R

Radon. A colorless, odorless gas that is a natural byproduct of uranium decay and dissolves in groundwater. Radon is a health risk when inhaled. While it can enter the home environment by escaping from dispensed groundwater, it is a more serious danger when it enters the home as a gas through cracks in the foundation.

Regenerant. A concentrated solution that is passed through a treatment device to remove retained contaminants and restore the contaminant removal capacity. See also **regeneration**.

Regeneration. A maintenance process that restores the contaminant removal capacity of media. Regeneration may involve using a concentrated solution, termed the regenerant, that is passed through a treatment device to remove retained contaminants and restore the contaminant removal capacity. Regeneration is sometimes mistakenly referred to as backwashing. See also **backwash** and **contaminant removal capacity**.

Resin. A petrochemical shaped into small beads that exchanges unwanted ions in water with less objectionable ions. The exchange occurs in an ion exchange device such as a water softener or anion exchange unit.

Resin tank. The main component of a water softener or demineralizer that contains the ion exchange resin.

Reverse osmosis (RO). A process that uses applied pressure to reverse the flow of water in the natural process of osmosis. In reverse osmosis, water flows through a semipermeable membrane from a more concentrated solution to a more dilute solution. See also **osmosis**.

RO. See **reverse osmosis (RO)**.

S

Sand. Soil particles between 50 and 2,000 microns in diameter.

Secondary drinking water standards. Drinking water standards set by the U.S. Environmental Protection Agency (EPA) concerning drinking water contaminants that are not considered hazardous to human health but that affect taste, odor, or color or cause staining on plumbing fixtures or clothing. The EPA does not require compliance with these standards, but they are enforced by some state governments. See also **primary drinking water standards**.

Sediment. Eroded soil and rock material.

Septum. A porous membrane in a precoat filter that can be fabric, bronze, stainless steel, or a wire-wrapped cylinder. The septum supports the filter aid. See also **precoat filter**.

Sequestering agent. A chemical that "ties up" or combines with objectionable substances in the water supply, thus minimizing their negative impact on water quality.

Service flow rate. The volume of water that flows through a specific area of a household water distribution system per minute, per hour, or per day.

Silt. A soil particle having a diameter in the range of 2 to 50 microns.

Soda ash. The common name for sodium carbonate, a chemical compound used to raise the pH of acidic water to prevent corrosion. The chemical symbol for soda ash is "Na_2CO_3." See also **corrosion**.

Sodium hydroxide (also called caustic or lye). A white, brittle solid that is used to raise the pH of acidic water in order to prevent corrosion. Sodium hydroxide is a hazardous chemical and must be handled and stored with care. The chemical symbol for sodium hydroxide is "NaOH." See also **corrosion**.

Softening. The process of exchanging calcium and magnesium ions in water for sodium or potassium ions to prevent hardness. See also **cation exchange** and **hardness**.

Solvent. Any substance capable of dissolving another substance.

Submersible pump. A pump designed to allow the motor to be submerged in a well below the pump intake.

Superchlorination. A method of chlorination that produces a free chlorine residual of 3.0 to 5.0 milligrams per liter—approximately ten times higher

than the residual from routine chlorination. At this concentration, the necessary contact time for disinfection is reduced and water has a very strong chlorine smell and taste that is usually removed with an activated carbon postfilter. See also **contact time** and **free chlorine residual**.

Surface area. The area of filter material that untreated water contacts. In a media filter, for example, the surface area includes the uppermost surface of the filter media.

Suspended solids. Particles in water that may either be visible as individual particles or give water a cloudy appearance. Suspended solids include silt or clay; decayed plants or other organics; iron, manganese, or sulfur particles; and microorganisms. If not removed, they may clog certain treatment devices or shield microorganisms from disinfection.

T

TDS. See **total dissolved solids (TDS)**.

THMs. See **trihalomethanes (THMs)**.

Threshold-odor concentration. The minimum concentration of an odorous substance that can be detected.

Tincture. A substance in a solution of alcohol.

Total acidity. A water quality parameter that measures the water's ability to neutralize alkalinity. It can be measured with a water test.

Total coliform. See **coliform bacteria**.

Total dissolved solids (TDS). A general water quality parameter that is a measure of the quantity of dissolved organic and inorganic chemicals in water.

Toxic. Harmful to human or animal life. Toxic substances may cause health effects through chronic (long-term) consumption of small concentrations. Exposure to high concentrations may cause immediate health effects.

Trihalomethanes (THMs). Chemicals that form when naturally occurring organic materials combine with free chlorine. Humic acid from decaying leaves forms THMs when it reacts with chlorine. THMs are most common in surface water and are linked to increases in bladder and rectal cancers.

Turbidity. A measure of the cloudiness or opacity of water due to suspended solids. See also **suspended solids**.

U

Ultraviolet (UV) light. Radiation ranging from 60 to 390 nanometers in wavelength. Ultraviolet light has a shorter wavelength than visible light and a longer wavelength than x rays. At wavelengths between 200 and 300 nanometers, it has a strong germicidal ability and is used to disinfect drinking water. Most UV lamps used in home water treatment produce light in the range of 260 nanometers.

Unloading (same as dumping). The process by which contaminants are released from a treatment device into treated water. Unloading occurs when a device is allowed to operate beyond the point of breakthrough and may result in a higher contaminant concentration in treated water than in untreated water. It is especially important in adsorption and ion exchange processes. See also **breakthrough**.

UV. See **ultraviolet (UV) light**.

V

Venturi injector. A device used to add chemicals to a water supply. The device looks like a short length of pipe that narrows significantly in the center. As water passes through the narrow part of the injector, a pressure differential is created that draws the chemical into the water line.

Virus. One of a group of microscopic, self-reproducing organisms that infect humans, animals, and plants with disease. Viruses range from about 0.01 to 0.4 micron in diameter.

VOC. See **volatile organic chemical (VOC)**.

Volatile. Readily vaporizable.

Volatile organic chemical (VOC). Chemicals that evaporate and may cause adverse health effects when inhaled. When water is contaminated with volatile organics, the chemicals may escape from the water, especially when it is heated, agitated, or sprayed as it is during cooking, in washing machines, or during showers.

Volatilization. Loss of a substance through vaporization.

W

Water pressure. The pressure water is under as it moves within a household water distribution system.

Water softening. See **softening**.

Well screen. A filtering device used to keep sediment from entering a water well.

Z

Zeolite. A synthetic resin that is a crystalline formulation of aluminates and silicates. Depending on how it is prepared, zeolite can be used either as an oxidizing agent or ion exchange resin.

Zone of adsorption. In adsorption devices, the part of the media column where adsorption is occurring. As upper parts of the column become saturated with contaminant, the zone of adsorption migrates down the column. See also **adsorption**.

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